Sedimentation and Salmonids in England and Wales

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Statement of use
This report will be of interest to all organisations involved in the protection of salmon and trout fisheries. It will be used within the Environment Agency to develop a strategic approach to reducing sediment pollution affecting salmonid fisheries.

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EXECUTIVE SUMMARY

Dr. Fred Theurer of the United States Department of Agriculture, Natural Resources Conservation Service (NRCS) conducted a three month OECD-funded study visit at the invitation of the Environment Agency and the Soil Survey and Land Research Centre. The purpose of the project was to collate evidence on whether fine sediment from rural land is affecting salmon and trout spawning habitats in England and Wales.

The work follows widespread concern as salmonid populations have fallen to critically small numbers from the abundance of historical times. More than 120 fisheries specialists were contacted during the study both inside and outside the Environment Agency. Dr. Tim Harrod (SSLRC) accompanied Dr. and Mrs. Theurer to familiarise them with soil and water management conditions in this country.

Agriculturally derived fine sediment is recognised as a major threat to salmonid stocks in the USA. As a result of their study visits, the authors believe that sediment pollution is widespread in England and Wales and is having a deleterious effect on salmonid fisheries. Most riffles examined during the study had significant amounts of fine sediment in the pores of the gravel. However, it became apparent during the work that there is little hard, documentary evidence available to indicate the scale of the problem.

Much of the time was devoted to briefing Agency staff on how fine sediments affect egg and alevin survival, based on work done in the USA. The principal process identified is sediment intrusion into gravels after a redd has been constructed. The rate of intrusion depends on suspended solid concentrations. A significant source of fine sediment in rural areas is from agriculture. It was noted that sediment generation in England and Wales is encouraged by the absence of any culture of integrated soil and water conservation in rural land management.

During the site visits, it was clear that Environment Agency staff have identified bank erosion as a source of sediment and have several projects in hand to deal with it. However, there are few tailored to deal with the substantial source of sediment that originates away from the river corridor.

The key recommendations of the study are that the Environment Agency should:

- undertake research to gather the necessary evidence to determine the impact of sediment pollution on salmonid fisheries in England and Wales. This should be coordinated by the National Salmon Centre;
- improve communication between Agency functions in order that an holistic approach can be taken to tackle sediment pollution; and
- seek outside expertise from both inside the UK and from abroad.

1 PURPOSE

Dr. Fred Theurer was invited by the Environment Agency (Agency) of England and Wales and the Soil Survey and Land Research Centre (SSLRC) of Cranfield University to visit the United Kingdom (UK). The primary purpose of this project was to assess the impact of fine sediment originating from the rural landscape on salmonid spawning habitat. The trip was sponsored by the Organization for Economic Cooperation and Development and the U.S. Department of Agriculture, Natural Resources Conservation Service (NRCS). The work was not intended as a comprehensive review of all evidence but more as a scoping exercise particularly whether sediment from agricultural lands is having an impact on salmon and trout fisheries.

The Environment Agency sponsored Dr. Tim Harrod from the SSLRC to accompany Dr. Theurer and Ms. Margaret Theurer in order to familiarize them with UK soil and water management conditions. This report describes the areas visited, the linkages between rural land use and the decline of salmonids, and the technical relationships between agriculture and salmonids. Finally, the report presents the findings of the investigation and recommendations for future actions that may be taken.

Dr. Theurer is a registered professional civil engineer in the State of Pennsylvania and has been with NRCS for 38 years. He has extensive experience studying the effects of agriculture on salmonid habitat in the Pacific Northwest. In particular, he has studied and published papers on: (a) sediment yield from agricultural watersheds (catchments); (b) their fine sediment effects in salmonid redds; and (c) the effects of the loss of riparian vegetation, stream flow withdrawals, and irrigation return flows on water temperature and its effects on fisheries.

Dr. Harrod has been a Soil Scientist with SSLRC for 32 years. He is based at North Wyke Research Station, Okehampton, Devon. Dr. Harrod has extensive experience of soils and their hydrology, surface processes and soil erosion. In the last 10 years, much of his time has been given to studies of the impacts of soils and land use on the aquatic environment. An example of the work is that on pesticide pollution in west Cornwall, which resulted directly in the withdrawal from agriculture of the pesticide aldrin.

Ms. Margaret Theurer is retired from the NRCS where she worked as a Program Assistant for the Watershed Projects Division. She worked primarily with the Watershed Protection Program and the Emergency Watershed Program. She has worked with the Agriculture Research Service and the Soil Conservation Service (now NRCS) at various locations in the US.

Site visits were important and necessary to this effort. Equally important was the opportunity to consult with Agency staff and other knowledgeable UK scientists concerning their views regarding the suspected decline of salmonids in England and Wales, and any possible connection with erosion and its subsequent sediment originating from anywhere within the entire catchment.

2 SITE VISITS

2.1 Introduction

Numerous site visits were made in each of the regions in England and Wales over a ten-week period. The format of these visits evolved as the weeks passed. It quickly became apparent that a briefing paper, which is Section 1 of this report, was needed to inform local Agency staff about the purpose of the visit and the type of information the authors was seeking. Another change in approach that occurred as time passed was the percentage of time spent in the field. While time in the field was important, increased time listening to the thoughts and concerns of the Agency personnel proved to be invaluable. While most Agency field staff recognised that a fishery problem existed, they were not sure of the specific causes (e.g., lack of dissolved oxygen within the redd) or the possible connection to land outside the river system. There was common concern over damage to banks by livestock as a source of sediment entering streams.

On several occasions cementation, compaction or consolidation of the gravel was mentioned, commonly with the comment that it was thought to have come about in recent years. Since both chalk streams and acid-to-neutral streams were involved, the varied hydrochemical environments suggest more than a single cause. No clear-cut example was seen, although a riffle made up of uniformly sized angular, tabular stones in the North Tyne had something of a weakly resistant surface. In 1995, one of the authors examined a case of hard, cemented bed in the Tamar where the gravel required disruption with power machinery. This site proved to be subsoil, where the gravel was pedologically cemented by manganese and iron oxides, subsequently exposed by meander migration and bank erosion. Such cemented subsoil is not uncommon at or about permanent watertable levels and is well recognised by farmers. It has a number of dialect names—“roche” in North Wales, “rab” in Pembrokeshire and “black ram” in southwest England.

Field staff also did not understand the physical processes involved in redd building and the hydrodynamics within the redd during the incubation period. The format of the visits included intensive discussions with Agency staff to determine: (1) what they felt the problems were; (2) an education session on the physical processes taking place within salmonid redds; and (3) finally visits to the field.

During the field visits, the fine sediment content of the gravel in riffles was explored, wherever possible. This was done by careful digging or by slowly working a foot into the gravel. At most sites, the latter produced a re-suspended plume of fine sediment, which remained in suspension despite the low discharges prevailing. (Only organic matter, silt, or clay behaves that way). Digging provided hand samples that revealed fine sediment filling the pores of most of the gravel examined. This is an *ad hoc* approach, useful in giving an overall impression of whether the gravel have been intruded by fine material. It is no substitute for examining bed sediment by systematic freeze-coring. Freeze-coring can indicate the rate of fine sediment entering the egg zone when carried out on prepared artificial redds near the end of the incubation period. Use of mineralogical and other fingerprinting methods on the fine sediment thus obtained holds the prospect of identifying sources.

The following is a brief summary of the findings of the visits to each region.

2.2 South West and Southern Regions, September 22-26, 1997

Visits to field sites in the Southern and South West Chalk catchments included the Hampshire Avon and Rivers Itchen, Test, Nadder, and Wyle. In addition, the authors were given a light aircraft overflight of the Test and Itchen catchments. The flight provided a birds-eye view of land patterns and uses in the catchments. This revealed the numbers of gravel workings, fish and cress farms and maize fields close to the river. Several outdoor piggeries in the catchment were revealed from the aircraft, at least one approaching close to the River Test floodplain. With one exception all gravel examined in the beds of the Avon, Nadder and Wyle showed convincing signs of intrusion of fine sediment (organic matter or clay or silt sized mineral particles) into the gravel interstices. Flow pathways, where turbid runoff from arable fields had been observed entering road drains discharging into the River Nadder, were seen. No photographs or measurements of flow or suspended solids were available.

Some time was spent visiting David Stuart who owns some land adjacent to the River Test. He said when he first purchased the property several years ago, countless salmon returned each year to spawn near his house and further upstream. He was able to catch many salmon during the fishing season. Now, since a fish farm began upstream a few years ago, the organic detritus has destroyed the runs that used to return year after year.

A large watercress farm was visited and the processes described by the staff. The crops are grown in shallow water, on concrete beds constructed on valley bottoms at the level of the groundwater-table. The beds have a slight down valley gradient. They are irrigated with water that is often borehole derived. Nutrients may be added to the water. Rooting medium is placed on the beds and seedlings are transplanted into it. Some farms only use clean gravel and sand, containing negligible silt or finer material, as the bedding material, others use peat mats. In summer, the crop is picked or machine cut about every three weeks. The beds are cleaned after about every third crop. This operation releases effluent from the beds into the culverts draining them. This includes suspended sediment, particularly when peat is used, also plant detritus, and incidental algal material, which can form in the nutrient rich water. Sediment is likely to enter adjacent watercourses unless there are adequately designed and managed settlement facilities. Other activities involved in watercress farming, such as cleaning and maintenance of culverts, settlement lagoons and other equipment, can present the hazard of sediment release.

A half-day was spent touring a local military tank training range in the River Frome catchment to view that site’s effects on runoff and sedimentation and the efforts at soil conservation. Substantial attempts have been made to protect the River Frome from turbid runoff escaping from the testing areas, notably by the construction of stilling lagoons. However in very wet weather, it is likely that there is spill over and some discharge to the river. The system’s efficacy is reduced if the lagoons are not cleaned out periodically. However, this causes a conflict among conservation interests because reeds and their associated insect fauna colonize the lagoons.

Another half-day was spent walking fields in the River Frome basin to study the drainage patterns in the Chalkland area. Chalk soils are very permeable and the patterns of fields have been established over the centuries. The main pathways of runoff from arable land appear to be via an extended drainage net. This pathway not only follows the natural dry valleys, but also is often diverted along, or contained by, both ephemeral and long-term man-made features. These include hedges, infield furrows, tramlines and wheelings, with runoff often exiting via field gateways onto tracks, roads, etc. and reaching watercourses through the road drainage system.

Finally, a Chalkstream Workshop on Siltation and Salmonids was held at Blandford Forum including Agency staff and members of Institute of Freshwater Ecology (IFE), Centre for Environment, Fisheries and Aquaculture Science (CEFAS) and the Game Conservancy. Issues surfacing during the site visits included stream bank degradation, maize growing, waste from cress beds, waste from fish farms, and diffuse agricultural runoff.

Some information presented at the workshop indicated that:

- there is very limited salmon egg survival in chalk streams;
- gravel cleaning improves egg survival; and
- a study in the River Piddle catchment (Walling and Amos, 1994) has traced the main source of fine sediment to arable land.

Some restoration efforts are being taken such as gravel cleaning and stream bank restoration to narrow the river and increase water velocity flowing over spawning gravel. The Agency's "Landcare" project in the Hampshire-Avon area encourages techniques to reduce soil erosion and turbid runoff. There was considerable discussion about the complexity and degree of the problem of a declining salmonid population and whether agriculture is a contributor.

Conclusions drawn from the workshop (Hamilton, 1997) are that:

- the Region has significant salmonid stream catchments with characteristics that provide a high risk of impacts from sedimentation;
- significant anecdotal evidence on potential impacts of sedimentation is available;
- there is very limited data and hard evidence of direct impact of sedimentation on salmonid populations; and
- some prevention and restoration work is going on.

October 29, 1997

A visit to Phil Griffiths and Richard Horsfield at Worthing in the Southern Region was delayed until late October. The River Rother has a run of sea trout. Problems in this catchment include low flows resulting from drought conditions and abstraction (Hamilton, 1997). Evidence exists of sediment loaded runoff discharging during wet weather from land where potatoes, and other cash crops are grown. This is summarised in the report on the River Lod (see Section3.3.3). There also appears to be a question about what kind of fishery is most desirable in the area, salmonid or coarse fish.

Table 2-1 Southern and South West Personnel

Place	Date	Personnel
Rivers Test and Itchen	23/9	Lawrence Talks, Agency, Winchester, Southern Region Stuart Taylor, Agency, Winchester, Southern Region David Stuart, Landowner
Hampshire Avon River Wyle River Nadder	24/9	Paul Bryson Andy Strevens Agency, Blandford Forum

Place	Date	Personnel
Blandford Meeting	25/9	Stuart Bray, Agency, Exeter Roger Hamilton, Agency, Exeter Richard Smith, Agency, Exeter Graham Lightfoot, Agency, Blandford Andy Strevens, Agency, Blandford Bob Huggins, Agency, Blandford Lawrence Talks, Agency, Winchester Stuart Taylor, Agency, Winchester Suzanne Fewings, Agency, Waterlooville Dave Willis, Agency, Reading Richard Copas, Agency, Reading Nigel Milner, Agency, Salmon and Trout Centre, Cardiff Ted Potter, Centre for Environment, Fisheries and Aquaculture Science, Lowestoft Bill Riley, Centre for Environment, Fisheries and Aquaculture Science, Lowestoft Mike Ladle, Institute of Freshwater Ecology, Wareham Stuart Welton, Institute of Freshwater Ecology, Wareham Dave Summers, Game Conservancy Trust, Fordingbridge Brian Shields, Game Conservancy Trust, Fordingbridge
River Frome	26/9	George Preston, Major (retd.), HQ Royal Armoured Corps, Bovington, Wareham, Dorest BH20 6IA Kevin Parsons, EA, Blandford Forum
Worthing	26/10	Phil Griffiths, EA, Worthing, Southern Region Richard Horsfield, EA, Worthing, Southern Region

2.3 Institute for Freshwater Ecology, Windermere, September 29 and 30, 1997.

Two days were spent doing an extensive literature search on the freshwater habitat of salmonids, including dissolved oxygen (DO) and temperature, and sedimentation of spawning gravel in the United Kingdom, at the Institute's library. A large number of publications are available and are listed in the bibliography of this report. Considerable expertise is available in the UK to study this problem.

2.4 Northumbria and Yorkshire Region, October 6-10, 1997

Site visits in this region included the Rivers Ouse, Ure, Swale, Cover, Aire, Calder, North Tyne, Coquet, Derwent, and Costa Beck. A final day was spent in the York Agency office consulting with staff. Problems identified were accelerated stream bank degradation from livestock, major gullying of steep hillsides resulting from overgrazing by livestock and the introduction of grips. Additionally, erosion and sedimentation from forestry operations was present, and erosion from arable land was seen. Minimal work has been done on freeze-coring and those freeze-cores taken were from the undisturbed streambed, not redds or artificial redds. No water samples had been taken in conjunction with the freeze-coring.

We were shown a very active reach of the River Coquet, a Site of Special Scientific Interest (SSSI). A gravel removal operation had been and still was in operation immediately downstream of this reach. The authors believe that the gravel removal likely was responsible for the active meandering within this reach. However, Mr. Wesley Smith from English Nature believed that the active bank meandering provided excellent habitat for birds. Again, examination of several riffles in the Coquet and North Tyne indicated fine sediment intruded into the gravel.

The River Ure was visited in the Rippon district at West Tanfield and Jervaulx, followed by Coverdale. The visit introduced upland catchments, which are heavily stocked with sheep. Evidence was seen of soil erosion control by fencing to exclude livestock, both on riverbanks and on higher parts of the landscape. A stretch of the River Cover badly affected by gravel repositioning using a power machinery was seen, along with examples of gullying of the moorland, triggered by the digging of drainage grips. Complaints from angling groups were reported regarding sedimentation of upland reaches of the River Wharfe around Grimwith Reservoir, Grassington.

Sedimentation of the upper reaches of the Yorkshire Derwent is seen as an issue by Environment Agency staff. The correspondence quoted in Section 3.3.6 demonstrates its generation by ill-managed forestry working on the Sutherland Beck. The bed of the Derwent in the Forge Valley is smothered with fine sediment. There are several possible sources. Forestry operations are active upstream. Rides and tracks in the catchment see leisure use by the public with 4-wheel drive vehicles and motorbikes. Sugarbeet, potatoes and cereals are grown on light soils on slopes near the river, in most cases with the land worked up and down the slope. The Costa Beck near Pickering receives some discharges from agricultural land drains, agricultural ditches, and road runoff. In addition, any associated sediment from urban sources can reach its head via road drains.

Table 2-2 Northumbria and Yorkshire Personnel

Place	Date	Personnel
Rivers Ouse, Ure, Cover, and Swale	6/10	Ann Sansom, Agency, York Ivan Ingles, Agency, York
Rivers Aire and Calder	7/10	Pat O'Brien, Agency, York
Rivers Coquet and Tyne	8/10	Phil Rippon, Agency, Newcastle upon Tyne Jon Shelley, Agency, Newcastle upon Tyne Wesley Smith, English Nature
Costa Beck River Derwent	9/10	Roger Martin, Agency, York

2.5 Northwest Region, October 13-17, 1997

The week in the Northwest began in Warrington, where the authors made a presentation on the purpose of the visit to the region and in turn were briefed on activities there. A database has been developed of the river systems in the UK. The River Habitat Survey is CD-based with 5,000 random sites in England and Wales. A Sustainable River Management Project is underway to address issues of overgrazing of riverbanks, overstocking and arable practices, and the use of fertilisers, pesticides, and sheep dips (Fisher, 1997). Later in the day, the authors visited the Manchester Airport runway extension to view conservation efforts during construction along the River Bollin. Additional areas visited included the Rivers Bollin, Ribble, Lune, Eden, and Eamont. The problems observed were primarily accelerated stream bank degradation resulting from livestock. Considerable runoff from livestock yards was also observed. Very little work, if any, had been done on freeze-coring or water sampling. Agency personnel had primarily involved themselves in the river system and were not aware that sediments could result from erosion of lands away from the river. All were enthusiastic and anxious to take steps to improve the streams.

Two mornings of this week were spent consulting with Dr. Paul Carling at the University of Lancaster discussing sedimentation problems. Dr. Carling has extensive knowledge in this area and has written numerous papers which are listed in the bibliography. He spoke of plans to host a symposium on sedimentation and geomorphology in the UK. Harriet Orr, a graduate student of Dr. Carling, is studying river management under changing climate and land use conditions. She is pursuing a study of a perceived rainfall shift in the UK from the summer to winter time.

Table 2-3 Northwest Personnel

Place	Date	Personnel
Warrington and River Bollin	13/10	Miran Aprahamian, Agency, Warrington Mark Diamond, Agency, Warrington Ian Dunhill, Agency, Warrington Mark Fisher, Agency, Warrington Dawn Grundy, Agency, Warrington Sara Jones, Agency, Warrington Sarah Lester, Agency, Warrington Marc Naura, Agency, Warrington Jim Walker, Agency, Warrington Elaine Fisher, Agency, Warrington
Rivers Ribble and Lune	14 and 15/10	Jonathan Shatwell, Agency, Preston
University of Lancaster	15 and 16/10	Dr. Paul Carling, Geomorphologist, consultant Harriett Orr, graduate student, consultant
Kendal	16/10	Liz Black, Agency, Kendal Mike Dickson, Agency, Kendal John Foster, Agency, Kendal Graham McKeague, Agency, Kendal Dave Pearson, Agency, Kendal Andy Knipe, Agency, Kendal
Rivers Eden and Eamont	17/10	Cameron Durie, Agency, Carlisle Jane Atkins, Agency, Carlisle Keith Kendal, Agency, Carlisle

2.6 Consultants and the Thames and East Anglia Regions, October 27-31, 1997

This week was used to also visit consultants. Naismith *et al.* (1996) emphasize that the salmonid populations had declined in the River Torridge which is in the Southwest Region. Although their report does not specifically say agriculture is a major cause, it does suggest there is a connection between sediment from agricultural land use and embryo survival. The executive summary states: "In-situ salmon embryo bioassays suggest that there is an impact on embryo survival in intensively farmed sub-catchments, relating to spawning gravel quality. River-bed gravel in these areas contained fine sediment concentrations likely to be damaging to salmonid embryo survival and interstitial dissolved oxygen (DO) levels in these gravel were low enough to be lethal to embryos. However, the processes by which sediment is supplied to and deposited in watercourses are complex and it is difficult to infer whether this reflects an historical change in sediment loads."

The authors also consulted with Dr. Pam Naden, Institute of Hydrology. Dr. Naden is involved with the Land-Ocean Interaction Study (LOIS) and has been responsible for the addition of a sediment yield model that can distinguish between sediment originating from arable land and that from non-arable land. Dr. Ros R. Boar of the University of East Anglia was also consulted and her work was discussed (Boar *et al.*, 1994)

Site visits were made in the area around Norwich on the final day. Fine mineral sediment was seen binding gravel in the River Bure around Corpusty. Along the River Glaven, sediment from agricultural fields enters the watercourse, causing some downstream flooding. It also affects roads and mill operations, necessitating frequent dredging. (Reports indicate that about 180 tonnes have been removed from the race of Letheringsett Mill [surface area about 135 m^2]. This was its second cleaning in two and a half years).

Table 2-4 Consultants and Thames and East Anglia Personnel

Place	Date	Personnel
Water Research Centre	28/10	Dr. Ian Naismith, Agency consultant for the River Torridge
Institute of Hydrology	28/10	Dr. Pam Naden, Scientist for LOIS, consultant
University of East Anglia	31/10	Dr. Ros Boar, Geomorphologist, consultant
Norwich: River Wensum, Bure and Glaven	31/10	Graham Gamble, Agency, Norwich Mike Norton, Agency, Norwich

2.7 Welsh Region, November 3-11, 1997

Considerable time was spent during this nine-day trip explaining to Agency personnel the physical processes taking place in salmonid redds and the effects of sedimentation on spawning gravel. As was the case in England, Agency personnel received the information enthusiastically. It seemed to confirm their suspicions of the one of the causes for a decline in salmonids. Site visits in Wales included the Rivers Usk, Wye, Dee, West Cleddau, and the Afon Garw.

Three days were spent visiting sites in the Usk catchment and the lower, middle, and upper Wye catchment. Issues that surfaced during the site visits were accelerated stream bank degradation resulting from livestock and erosion from agricultural lands producing cereals, potatoes, and onions. Fine sediment intruded into the gravel interstices was identified and demonstrated by digging in riffles in the Wye and its tributaries around Newbridge and Glasbury. Only gravel in the acidified headwaters of the Wye above Llangurig appeared to be free of fine sediment.

An incident had been reported in August 1997 of sedimentation to the Coughton Brook (see Appendix B) from an overnight rainfall onto fields where potatoes had recently been harvested. Highly turbid water entered the watercourse by way of the road and roadside drains (Purvis, 1997).

One day was spent in the Maerdy area visiting selected spawning sites in the Middle River Dee. Stream bank erosion and siltation of gravel in the River Dee was observed. A day was spent in the Bangor area observing a forestry area that appeared to be well managed with respect to containing any sediment.

A gravel processing operation was visited that used a settling pond before discharging their wash water into the river. The settling pond dike adjacent to the river had been breached recently. Sediment deposition resulting from the breached settling pond was reported to have been seen for several kilometers downstream in the River Dee although no photographs had been taken and no incident report had been prepared.

A day was spent in the Haverfordwest area observing streambank erosion from cattle and sheep and siltation problems. Other concerns noted were fish farming and cold water temperatures resulting from dam releases. Finally, an opencast mining operation was visited. Serious efforts are being made to restore an area in the Afon Garw where open cast mining has been closed down (Todd *et al.*, 1997). It was noticed at the time of our visit that reseeding of the disturbed areas was not done and evidence of significant fine sediment from the disturbed area was visible passing through the small settling pond in the river.

The first substantial rains of the autumn occurred during this time in Wales. The impacts of cattle and sheep poaching impermeable pastures then became readily apparent. The associated turbid discharges and the management practices encouraging them are summarised in Section 3.3.1 (Todd *et al.*, 1997).

Table 2-5 Wales Personnel

Place	Date	Personnel
Rivers Usk and Wye	3-5/11	Peter Gough, Agency, St. Mellons Bill Purvis, Agency, St. Mellons Alan Pryce, Agency, St. Mellons John Coombe, Agency, Monmouth Richard White, Wye Foundation
River Dee	6/11	Richard Brassington, Agency, Bangor Ian Davidson, Agency, Buckley Richard Cove, Agency, Buckley
Bangor	7/11	Rob Thomas, Agency, Bangor
Haverfordwest; River Cleddau	10/11	Bob Merriman, Agency, Haverfordwest Roger Pratt, Agency, Haverfordwest Mike Todd, Agency, Swansea
Swansea; Afon Garw	11/11	Jerry Weeks, Agency, Swansea Mike Todd, Agency, Swansea

2.8 Consultant and Midlands and Thames Area, November 12-14, 1997

One afternoon was spent consulting with a Professor Geoff Petts at Birmingham University to discuss geomorphology and salmonid redds. He has done considerable research with respect to sedimentation in general and some research on sediment in redds. His unpublished work would be of interest to the profession. A thought-provoking remark he made during our discussion regarding the geomorphological conditions of stream systems in England was: "Things are so unnatural in England that they are considered natural."

A second afternoon was spent at the Regional Fisheries Managers meeting in Reading to describe the project's progress to date. The presentation included a brief description concerning the sedimentation processes in salmonid redds and the evidence collected thus far of erosion from agricultural land.

A day was spent in the Thames region in both chalk and limestone areas. The discussions focused on the Rivers Kennet, Lambourn and Coln. The rivers support a brown trout population, both wild and stocked, and coarse fish as well. Issues that surfaced during the visit were intensive landuse, water abstraction, and fish passage problems due to low flows.

Intrusion of fine sediment into pores in the gravel became evident upon digging in riffles in the Rivers Lambourn and Coln. Agency staff reported that turbid runoff originating on farmland is transported along minor roads close to the River Lambourn. Indirect evidence of its flow (rilling and re-deposition of sand and small stones) was seen down a track and into a backwater ditch. An outdoor piggery was identify in the same catchment. It has a high probability of turbid discharge in wet weather from its lower end that could result in water and sediment discharging onto the road and into the watercourses. A recently cut redd was seen in the River Coln.

Part of the River Restoration Project on the River Cole was visited. The in-river and riverbank work was being conducted to a high standard. However, reseeding of the immediately adjacent parts of the floodplain had been done too late in the year for adequate grass cover to establish. Consequently, the soil of the floodplain surface will be unprotected until the spring. Should any bankfull floods occur, this will present a high and unnecessary risk of sediment being added to the river.

Table 2-6 Midlands and Thames Personnel

Place	Date	Personnel
University of Birmingham	12/11	Prof. G. E. Petts, Fluvial Geomorphology, consultant
Reading	13/11	Paul Raven, Agency, Head Office Tony Owen, Agency, Head Office Craig McGarvey, Agency, Head Office Guy Mawle, Agency, Head Office Richard Wightman, Agency, Head Office John Adams, Agency, Anglian Chris Marsh, Agency, Midlands Steve Bailey, Agency, North East Mark Diamond, Agency North West Ian Johnson, Agency, Southern

Place	Date	Personnel
Reading (continued)	13/11	Stuart Bray, Agency, South West Roger Sweeting, Agency, Thames John Redmond, Agency, Thames Dave Clarke, Agency, Welsh Emma Churchill, Agency, Head Office Jerry Sherriff, Agency, Head Office Richard Streeter, Agency, Head Office
Wallingford: Rivers Kennet, Lambourn, Cole and Coln.	14/11	Dave Willis, Agency, Wallingford Bob Preston, Agency, Wallingford

2.9 South West and Midlands, November 17-21, 1997

One afternoon was spent visiting sites on the Rivers Axe and Yarty. The authors observed accelerated stream bank erosion and contrasts in water quality and gravel in non-intensively and intensively farmed catchments. Visual inspection suggested that the non-intensive catchments offer more favorable habitat for salmonids. Freshly cut sea trout redds were seen.

Daniel Nicholls, a PhD candidate at the University of Exeter partly funded by the Environment Agency, devoted a morning to a presentation on sediment dynamics in the River Torridge and their impacts on the salmonids. He presented an original, relatively easy method for sampling artificial redds that does not involve freeze-coring.

Mr. Nicholls' project is part of the response to the study of the impact of land use on salmonids in the Torridge catchment (Naismith *et al.*, 1996). The study did identify fine sediment and associated dissolved oxygen in bed gravel as being in concentrations likely to be damaging or lethal to salmonid embryos. They give mean suspended solid loads during wet weather events, from 1990-1992, for three intensively farmed grassland catchments as between 81 and 94ppm (maxima 600-1800ppm). In 1991, such events had a total duration of 950 hours (39.6 days). Assuming only half of these fell during the spawning season, reference to Figure 4-1 indicates that a substantial impact on egg survival would occur.

In the afternoon, the authors met with Arlin Rickard of the West Country Rivers Trust and Charles Innis who owns the Half Moon Inn, Sheepwash. The Trust is carrying out a funded project under the European Objective 5b. This project provides advice to farmers on ways to improve agricultural practices in the River Tamar catchment. The groups also visited field sites on the River Waldon. High turbid flow prevented examination of the bed gravel and observation of Daniel Nicholls' original redd sampling system.

On Wednesday, 19 November, fisheries managers from Devon, Cornwall, and North Wessex gave presentations on problems in their respective areas:

- *Devon*—There has been a decline in the salmonid fishery since the 1960's. There is a large amount of arable land in the area and siltation is a common problem. Piggeries, gravel working, overgrazing, and lack of riparian vegetation are of concern in the area. Rivers involved include the Axe, Yarty, Otter, Taw and Torridge.
- *Cornwall*—The authors were told that a number of the sites electro-fished in the county have no fish. Some cause for the lack of fish is due to previous industrial wastes while other causes

are likely due to sediment pollution from agriculture. The area is intensively farmed with livestock and has some arable land. The upper Tamar is the principal catchment suffering from sediment pollution from agriculture. Problems include bank erosion, water abstraction, weed growth, and pollution from the china clay industry. Rivers described were the Tavy, Lyd, Camel, Tamar, Plym, and Fal.

- *North Wessex*—Much of this area is low-lying with arterial land drainage and water abstraction. Gravel bedded reaches of the rivers are confined to the upper sections. There are many livestock farms, and arable farms where maize is a crop of some importance. The Bristol Avon is heavily managed and has a poor brown trout population. A project is currently under way to restore the fish habitat in the upper reaches of this catchment. Other rivers described were the Piddle and Parrett.

Thursday morning was spent in the Midlands visiting the Rivers Arrow and Alne catchment. Problems observed were accelerated stream bank degradation and excessive weed growth. The catchments contain considerable arable land that is mostly underdrained. Local staff saw intensified agriculture as the main reason for a decline of salmonid (and other) fisheries in these rivers. Again, where examined by careful digging, interstices of gravel in riffles contained silt, clay and organic sediment.

In the afternoon, the authors visited Professor Ian Foster of the University of Coventry. Professor Foster is conducting research, which traces the source of sediment, with reference to soil type and site (Foster *et al*. 1990, Foster and Walling 1994, Foster *et al.* 1996, Foster *et al.* 1998). The technique, sometimes referred to as fingerprinting, offers the possibility of identifying sources such as erosion from stream banks or catchment land surface; and erosion specifically from cropland or pasture, etc.

The final day was spent in Derbyshire interviewing Agency personnel regarding historic trends in salmonid populations in the Trent catchment.

Table 2-7 Southwest and Midlands Personnel

Place	Date	Personnel
Exeter: Rivers Axe and Yarty	17/11	Richard Smith, Agency, Exeter Andy Locke, Agency, Exeter
University of Exeter and West Country Rivers Trust: River Waldon	18/11	Daniel Nicholls, Graduate Student Richard Smith, Agency, Exeter Nigel Reader, Agency, Devon Arlin Rickard, WC Rivers Trust Charles Innis, Half Moon Inn, Sheepwash
Exeter	19/11	Richard Smith, Agency, Exeter Stuart Bray, Agency, Exeter Roger Hamilton, Agency, Exeter Nigel Milner, National Salmon and Trout Centre, Cardiff Nigel Reader, Agency, Devon Rob Robinson, Agency, Exeter Martin Williams, Agency, Cornwall Roger Merry, Agency. Wessex

Place	Date	Personnel
River Alne	20/11	Derrick Lippett, Agency, Tewkesbury Paul Hoban, Agency, Tewkesbury
University of Coventry	20/11	Prof. Ian Foster
Derbyshire	21/11	Keith Easton, Agency, Nottingham Jim Lyons, Agency, Nottingham

2.10 Final Briefing of Environment Agency Personnel, December 17, 1997

A final meeting was convened on December 17 in Bristol to present an overview of the findings and recommendations to appear in this report. Several presentations were made by those involved in organizing and carrying out the project. Mr. T. R. E. (Dick) Thompson of the Soil Survey and Land Research Centre (SSLRC), Cranfield University, addressed broad policy issues. Mr. Cecil Currin, State Conservationist, USDA, Natural Resources Conservation Service (NRCS), discussed U.S. approaches and experiences in land use and conservation. Dr. Tim Harrod, SSLRC, Cranfield University, presented evidence gathered during the project concerning land use practices and the sedimentation of streams. Finally, Dr. Fred Theurer, USDA-NRCS, presented the findings and recommendations that appear in this final report.

The second half of the meeting was devoted to discussion of the findings and possible actions to be taken.

Table 2-8 Final Briefing Personnel

Place	Date	Personnel
Bristol	17/12	Tony Owen, Agency, Bristol Chris Newton, Agency, Bristol Jackie Vale, Agency, Bristol Richard Smith, Agency, Exeter Stuart Bray, Agency, Exeter Nigel Milner, Agency, Cardiff Ted Potter, Centre for Environment, Fisheries and Aquaculture, Lowestoft Dick Thompson, SSLRC, Silsoe Tim Harrod, SSLRC, Okehampton Cecil B. Currin, USDA, NRCS, Amerherst, MA, USA Fred D. Theurer, USDA, NRCS, Beltsville, MD, USA Margaret Theurer, USDA, NRCS (Retired), MD, USA

2.11 Summary

The site visits fell into three categories: (1) field site visits; (2) Agency office visits; and (3) consulting scientist's office visits. Responses from personnel within each category were very much similar with few exceptions.

Almost all field site visits started with a field visit to a streambank erosion site. The Agency Fisheries personnel recognize streambank erosion and are attempting to stabilize the banks. However, they were not aware of the potential for fine sediment yield from sheet and rill or ephemeral gully sources, and did not understand the insidious and pervasive effects of fine sediment intruding into salmonid redds. They were not able to respond to inquiries on the rearing habitat regarding carrying capacity—either current or potential.

Fisheries Division personnel showed us sites where they were attempting to improve spawning by raking and water jetting the substrate. The sites did not show any evidence of cementation or hardening. Nothing was being done to keep the landscape from eroding and the fine sediment being transported to the stream. Raking and water jetting would probably be futile because it would encourage the salmonids to spawn where sediment would probably intrude during the spawning period and likely resulting in total mortality of the embryo and fry.

Some of the Fisheries Division personnel also installed artificial redds, cleaned the gravel substrate (water jetting), or raked the substrate in a few streams to collect data regarding fine sediment intrusion. However, in most cases, they were not installed during the spawning season so the data would be of limited value. They also took freeze-cores from the undisturbed substrate, which is of very limited value in understanding the role of fine sediment intruding into the redds.

Gravel in nearly all the riffles visited showed clear signs of fine sediment in their interstitial pores when examined by digging or other *ad hoc* methods.

Flood Defence personnel, who the authors met, were extremely knowledgeable in their recognized fields of expertise. However, they were not able to provide the basic hydrologic help necessary to predict the water and sediment yield from the catchment (rainfall/runoff relationships, hydrograph generation, and sediment yield). It was also evident that Water Quality staff do not treat sediment runoff from agricultural land as a pollutant. Some routine water quality monitoring is carried out for suspended solids as part of the compliance assessment with the EC Freshwater Fish Directive (CEC 1978). This sets an annual mean suspended solids standard of 25 mg/l. However, the monthly sampling program is not likely to capture the short-lived, but critical, spates that are carrying harmful concentrations of suspended sediment. Results are therefore likely to understate the impact of suspended sediment in spawning environments.

During site visits, there was little soil conservation practice evident on the landscape. However more recently it has been acknowledged that there are off-farm effects from soil erosion and that fisheries can be damaged, e.g. RCEP (1996) and MAFF (1997).

The consulting scientists were extremely knowledgeable in their fields of expertise and could be a valuable resource for the studies identified in this report. However, their individual scope of expertise is limited to narrow areas of their sciences.

While most Agency staff recognized that a fishery problem existed, they were unsure of the specific causes or the possible connection to land outside the river system. Once Agency personnel understood the connection between sediment in the stream and the land use in the catchment, they were able to describe several examples of sediment-laden runoff to rivers and streams. However, the authors found only one incident that was sufficiently well documented (Purvis, 1997) with enough evidence to serve as scientific proof of the connection between agriculturally-induced erosion and the presence of suspended sediment in the river. There was little direct evidence found by the authors of work having been done to show suspended sediment causing mortality of the embryo or fry within a natural or simulated redd. The authors requested Agency staff at all locations to begin collecting hard scientific evidence with measurements, pictures, and written reports to demonstrate this connection.

The authors did not find anyone who was taking the holistic catchment approach that is needed for collecting the necessary proof of the cause and effect relationships between agriculture and the decline of salmonids in England and Wales. The interconnections between the hydrological, hydraulic, geomorphological and fisheries biological sciences are extremely important.

The site visits only provided a few photographs and an occasional single suspended sediment sample. There is a need to provide hard, scientific proof of the connection between agriculture and the decline of salmonids. This proof includes: (1) photographic, measured suspended sediment samples, and written reports throughout England and Wales of incidents especially those occurring during the spawning period to establish the national scope of the connection between agriculture and suspended sediment; (2) installation of artificial redds at the beginning of the spawning period, monitoring for fine sediment intrusion during the spawning period, and freeze-core and laboratory analysis (including "fingerprinting") of water and sediment samples taken during the spawning period; and (3) analyses of the rearing habitats to determine the current carrying capacities by reach for salmonids and the spawning requirements necessary to approach these carrying capacities.

It is the authors' view that from their observations of land use in England and Wales, coupled with their experience with very similar salmonid problems in the Pacific Northwest and the limited amount of analytic data and analyses available during the visits, that sediment pollution is likely to be widespread and is likely to be having a substantial impact on salmon and trout fisheries. A detailed analysis will probably show that its causes and relative magnitudes, from both agricultural and non-agricultural land uses and from both the catchment and streambed and bank sources of erosion, varies from region to region. The connection between land use and the decline of salmonids deserves further study.

3 CONNECTION BETWEEN RURAL LAND USE AND DECLINE OF SALMONIDS

In exploration of the possible link between rural land use and decline of salmonids, the sources of fine, interstitial sediment should be addressed. Changes in land use in rural catchments, particularly following agricultural intensification, are believed to be the cause of accelerated sediment delivery, (e.g. Naismith *et al.*, 1996). Part of this report (see Section 3.2) examines the agricultural and other rural land use mechanisms that may increase fine sediment transfer from the land, and provides examples of them. However, some rivers and streams may be naturally prone to its generation. Although they have sufficient gravel to form riffles, these rivers and streams are cut in soft beds and banks that readily yield fine sediment during spates.

Rivers and streams on hard rocks with little or no superficial geological deposits are least likely to produce large amounts of fine sediment during spates. The slatey country of the Lake District and parts of Wales and Cornwall, are examples of this type of geology. At the other extreme are rivers in easily eroded, soft beds and banks with little or no gravel, as in some of the Midland clay vales. Some rock formations, such as the Carboniferous shales of the coalfields, easily weather to clay in some soil forming environments. Catchment hydrology can play its part too. Groundwater fed rivers, other things being equal, are less likely to have large suspended solid loads, than surface-water catchments. The Chalk of southern and eastern counties provides the most extensive examples of groundwater streams. In some of the Chalk valleys, upwelling groundwater has complicated the picture. Thick peat and soft algal marl cover much of the Test and Itchen floodplains, providing soft, readily erodable material that may add suspended sediment.

It should be noted that sedimentologists and soil scientists define *clay* as mineral particles less than 2µm and *silt* 2-60µm. *Sand* (60µm-2mm) is subdivided into *fine* (0.06-0.2mm), *medium* (0.2-0.6mm) and *coarse* (0.6-2mm) fractions. These definitions will be followed in this report. The looser use of silt to describe sediment finer than pebbles is best avoided. The clay and silt sized particles, once suspended, remain in the water column for a long time, even in still conditions, and make up much of the wash load of suspended solids in most rivers. Where present, suspended organic material may behave similarly. The sand fractions, on the other hand, largely move by saltation.

3.1 Historical Background

3.1.1 Salmonids in England and Wales

Netboy (1968) gives an historical account of the salmon in England and Wales. In the early 8th century the Venerable Bede commented that Britain "…had the greatest plenty of salmon..." The royal hunting forests, initiated by King Canute in the 11th century, included protection for salmon and trout. At the time of the Domesday Book (1086) fishery owners paid "…renderings…" to the crown. Often the value was quoted in eels (Easton, 1978). A good idea of the abundance of salmon at that time is in the common statement that renderings were "…one thousand salmon or one hundred eels."

The first legislation specifically dealing with salmon was in 1285, imposing closed seasons in the Trent/Ouse system. Thereafter, laws constraining fisheries were enacted from time to time.

However, even by 1714, only 17 rivers, the Trent/Ouse system plus the Wear and Tees, the Ribble, Mersey, Dee, Severn and Wye, were subject to severe controls on the size of salmon sold in London. Boar *et al.* (1994) (p68) note that in 1667, the Court of Mayoralty Book records that a closed season was ordered at Norwich, in an effort to conserve salmon populations. Easton (1978) also quotes Charles Cotton in "The Compleat Angler" (1676) calling the Trent "…one of the finest rivers in the world and the most abounding with excellent salmon." Willan (1936) records that at the same time the salmon were not always valued. Between 1622 and 1662, it was written that "before erection of weirs fresh salmon and other fish were so plentiful that hired servants would condition with their masters not to eat such fish above three meals in the week". Comments of this nature were commonplace. Netboy (1968) mentions at least 3 separate examples from Britain, plus others from France, Spain, Sweden, and New Hampshire. Accounts summarised by Netboy from across England and Wales prior to the Industrial Revolution show rivers overall well stocked with salmon. Martin, as late as 1785, noted that the Mersey "…greatly abounds with salmon…"

By the late 18th century, the Industrial Revolution was under way. With it went rapid urbanisation and population growth. Untreated wastes from factories and from the slums were discharged into the rivers as a matter of course. As well as killing eggs, fish and other life in the rivers, pollution presented barriers to migrating fish; both sea bound smolts and returning spawners. Water abstraction and the construction of weirs and dams compounded the degradation.

Easton (1978) reckoned that by 1800, salmon runs had started to decline in the Trent and its tributaries, notably the Tame. Salmon were numerous in the Thames at the start of the 19th century, but became absent by about 1830 (Mills, 1989). Through Victorian times, pollution of rivers in the swiftly expanding urban and industrial areas became increasingly acute. Easton gives several descriptions of severe pollution incidents in the Trent basin in the 19th century. The Tame was reported in 1867 as being almost fishless and contained no salmon in 1883. In 1869, the Inspector of Salmon Fisheries reported that only a quarter of the country that should support salmon produced any at all. Thereafter deterioration continued, if erratically. Despite repeated legislation starting in the second half of the 19th century, which aimed to control pollution and manage fishing etc., stocks of salmon have continued to decline. In 1968, Netboy reckoned that their aggregate number in England and Wales was probably less than a quarter of that a century before, when they had already declined severely from their pre-industrial state.

Away from the major industrial areas, conditions may have begun to change by the 19th century. Overfishing was rife. Vancouver (1808) lamented recent deficiency in the salmon fishery on the River Taw, deploring the taking of vast numbers of smolts, a thousand having been taken in a week at one point. Vancouver reported that, on occasion, young fry were fed to the pigs, and conditions covering servant hire, comparable to those noted above by Willan, were commonly recalled. Industry developed in many small rural towns as well as in the conurbations, and water was both an industrial material and a source of power. Young's (1877) list of seriously polluted salmon rivers includes several away from the large cities. It was: Axe, Camel, Dart, Dee, Dovey, Eden, Exe, Fowey, Kent, Ogmore, Plym, Rhymney, Ribble, Severn, Stour, Tamar, Taw, Torridge, Tees, Teifi, Teign, Towy, Trent, Tyne, Usk, Wear, Wye, and Yorkshire rivers.

The impact on trout of the Industrial Revolution's pollution and construction of barriers etc. is less well documented. Habitats were reduced and residual populations isolated in relatively unpolluted reaches and headwaters across much of the country. Severely polluted rivers, such as the Calder, lifeless for many years, have side streams nearby, as in Hebden Dale, which has brown trout populations still thriving. Movement of sea trout would have suffered in the same ways as affected migrating salmon.

Netboy (1968) concluded his review of England and Wales by saying that the tide of decline had been stemmed. Hindsight suggests this was optimistic. Not long after 1968, access by migrating fish into the Yorkshire Derwent was prevented. The flood barrier built at its confluence with the Ouse was constructed without a fish pass. The stocks in the Derwent were already in decline and it soon ceased to be a salmon and sea trout river.

The NRA (1996) Strategy for the Management of Salmon in England and Wales states the concern, which must be shown for salmon stocks in the northeast Atlantic. A number of salmon rivers in England and Wales have the legacies of problems stemming from the last century and the Industrial Revolution. The report recognises that those problems have continued through this century. Pollution from diverse sources, including urban and industrial, transport, agricultural practices, and forestry can all impact upon salmon. Similar concerns can be expressed over trout stocks, e.g. in the Alyn catchment, Clwyd (Milner and Jones, 1983).

In the last 30 years, these pressures have expressed themselves as further decline in populations in English and Welsh rivers; for example, the review of spring salmon by Gough *et al.* (1992). With the exception of the Coquet, the tone of the Agency's Salmon Action Plans is one of falling stocks—and the Coquet did not have much of a statistical basis to claim that the stocks were not still in decline. The Hampshire Avon decline started in the 1980s. The stock in the River Test is considered to be in real danger, as is that in the Itchen. The River Lune is described as having *once* been among the best salmon fisheries in the country. In Northumbria and Yorkshire, the NRA Salmon and Sea Trout Strategy (undated), observes that these fish have long been a major resource in the northeast of England. It also states that all of the rivers in the region have at one time supported their runs.

Although limited salmon restoration has been achieved, as in the Thames catchment, the present atmosphere over most of England and Wales is one of crisis for anadromous salmonids. It is the authors' view that, prior to human interference with rivers and the land, all gravel bedded rivers and streams in England and Wales would have carried salmonids. This view is supported by the diverse occurrence of residual wild brown trout populations in many isolated streams over much of the country, and by the historical sources quoted above. Over a century of legislation and improved practices have greatly reduced levels of pollution in many rivers from the Thames and Trent downwards (Mills, 1989), at great expense to the nation as a whole. There is an opportunity to refill these habitats with their indigenous fauna rather than having them colonised by inappropriate species, or remaining as clean but sterile rivers and streams such as exists in the upper reaches of the River Wye.

3.1.2 Rural land use changes

At the same time as overfishing, pollution, and industrial use of water was changing the aquatic environment, terrestrial land use was transforming. Inevitably, this had its impacts on the country’s rivers and streams. Prior to the Agrarian Revolution and the enclosure movement, the rural landscape remained largely in the feudal 3-field system. The 19th century and the first half of this century saw a steady consolidation and development of the new principles of farming. Away from the wetter areas dominated by livestock farming, arable agriculture was largely on mixed farms where farmyard manure from housed livestock was essential to maintenance of soil fertility. By modern standards, mineral fertiliser inputs were small. Agriculture remained labour intensive. Although mechanisation steadily progressed, horses continued to be the main source of power on most farms until the Second World War.

Siege conditions during the war brought massive public support for farming, which has remained in one form or another to the present. Over the same period, the tractor revolutionised farming, while the numbers of farm workers have fallen radically. Agriculture has intensified, become industrialised and more specialised. Farms and fields have gotten larger and machinery more sophisticated and powerful. The use of chemicals, particularly mineral fertilisers and pesticides, has become an integral to agriculture's success. On most farms, wet land was drained between 1940 and 1980. Many pastures were ploughed up during the war and subsequently stayed in arable use.

The 1950s and 60s saw mixed farming decline. Most annual crops are now grown on specialist arable holdings. In the last 25 years, technical and structural changes have had their effects. The need for precise application of agrochemicals means most arable fields are now tramlined. Development of fungicides has brought about the change from spring to autumn sowing of cereals. The price support system has encouraged the growing of oilseeds, in particular rape, and in recent years, set aside. In some ways, contact with the land and sensitivity to the seasonal changes in soil hydrological conditions, so critical to pollutant movement, have declined. This could be partly attributed to the use of more powerful machinery and the wider use of contractors.

Horticulture, although of limited extent, is important environmentally because it involves winter harvesting and the risk of runoff. It too has experienced widespread changes, including the introduction of stone and clod removal, bed growing and field-scale polythene covering. The globalisation of horticulture and the strength of the marketplace bring further pressures to this sector, which can encourage ill-timed use of the land.

Stock farming has seen similar expansion and intensification. Dairy and beef herds became larger and sheep numbers have increased dramatically, particularly in and around the uplands. Similarly, rearing of housed pigs and poultry has intensified. Concern over the welfare of housed pigs has encouraged outdoor piggeries on some farms, which, when ill-sited or poorly managed, can have adverse effects on the environment.

The main themes of change that have affected agriculture in the latter half of the 20th century have been mirrored in other aspects of rural land use. These include forestry, mineral extraction, and construction for transportation and urbanisation, as well as recreational use of the land. Mechanisation, technical, financial, and social pressures have transformed the speed and scale of activities and changes. These pressures have also reduced sensitivity to weather and ground conditions, which in the past modulated most aspects of rural land use and management. The power of modern machinery means that now work can proceed under most circumstances. An inevitable consequence of this is the ready generation of turbid water under wet conditions. Modern machinery produces wheelings and tracks, which form very efficient conduits for runoff transfer towards watercourses.

3.2 Land Use and Sources of Fine Sediment

Several examples of land use practices capable of releasing or transporting sediment to watercourses were observed during the field visits to the catchments as described in Section 2. These activities take place both on the stream banks and more widely throughout the catchment. Essentially such practices involve damage and disturbance of the soil. These practices can produce mud and slurried soil, and reduce the soil's infiltration capacity or provide pathways for enhanced transport of runoff to watercourses. Damage to the soil is caused by ill-timed or ill-sited use of the land. Mostly it takes place under wet conditions, by animals' hooves, cultivations, excavations and vehicles travelling on the land, and by people walking. Instances of documented evidence are referred to in the case studies described later. From observation and knowledge of land use in this country, it is clear that these exemplify practices and potential sources of sediment that are widespread nationally.

Damage to stream banks is commonplace on livestock farms whenever animals are allowed unrestricted access to the watercourse. Banks are trampled and poached so that any protective sward is broken or destroyed. Sometimes termed bank erosion, this kind of damage is clearly different from bank erosion by fluvial processes, such as meander migration. The former is irregular and scalloped in form, whereas natural erosion usually forms a vertical face and is linear or gently articulated. Most of the work done (e.g. NRA 1995b, Walker 1997) and awareness of Agency staff regarding fine sediment delivery is at present focused on streambed and banks. While bank erosion must be take seriously, as any sediment mobilised is immediately in the watercourse, the catchment *as a whole* receives little attention. However where considered, it can be shown to provide sources of sediment, as illustrated in the case study examples listed below (see Section 3.2.2.7).

In reports and papers provided by Agency staff and other individuals contacted, there was:

(1) very limited firm evidence of accelerated erosion of the landscape leading to a transfer of fine sediment (i.e., suspended sediment) to watercourses; and

(2) no firm evidence, other than anecdotal, of this fine sediment intruding into redds during the spawning period or depositing on the stream bed and actually causing fish kills either in the redds or in the rearing habitats.

The limited evidence of fine sediment in the watercourses is outlined in the case studies. In addition, there is some other circumstantial evidence (e.g. Boar *et al.* 1994, Photographs 9a and b) showing soil erosion by runoff adjacent to the River Wensum). In terms of area, the most extensive practices capable of releasing sediment are associated with agriculture, although agriculture certainly is not the only potential source.

There have been a number of attempts to address the impact of land use on watercourses, such as MAFF's "Code of Good Agricultural Practice for the Protection of Water" (1991), "Code of Good Agricultural Practice for the Protection of Soil" (1993) and the Forestry Authority's "Forest and Water Guidelines" (1993). In its 19th Report, “Sustainable Use of Soil” (RCEP 1996), the Royal Commission on Environmental Pollution considered these issues and recognised soil erosion as a source of sediment in watercourses with consequences for fisheries. The recently published MAFF (1997) booklet "Controlling Soil Erosion" lists sediment in rivers as damaging the spawning grounds of fish. The Agency's R&D Report P40 (1997) "Best Management Practices to Reduce Diffuse Pollution from Agriculture" considers in some detail 24 of the more important ones, several of which are pertinent to sediment and runoff control. The forestry guidelines are relatively detailed. They address the impact of sediment on spawning gravel. The MAFF codes are less specific in their recommendations for management practices.

3.2.1 Potential agricultural sources

3.2.1.1 Arable Farming

The soil is most vulnerable to accelerated erosional losses of particles in runoff during its preparation for sowing and planting, before the establishment of the crop’s canopy, and during its use and management after harvest of some crops. Runoff is encouraged by the production of fine, smooth seedbeds, by cultivation up and down slope, by bed working and damage to soils during late harvests, as with maize, sugarbeet and potatoes. In this country, techniques used in many parts of the world to prevent runoff and to conserve soil and water, such as contour cultivation or conservation tillage, are rarely implemented.

Soils with large fine sand and silt contents are most vulnerable, both because they are easily worked and favoured for tillage, and because they readily cap under rain impact and lose their surface infiltration capacity. This encourages runoff, which on slopes can lead to rill and gully erosion, generating sediment that may reach watercourses. Less obvious, but probably more frequent and widespread in occurrence, is diffuse, turbid runoff which fails to cut channels (sheet and rill erosion) but which flows overland to watercourses or reaches them after infiltration into field drains.

The Coughton Brook (Appendix B), River Lod (Section 3.3.3) and Mount's Bay (Section 3.3.4) case studies provide examples of sediment affecting rivers and streams following erosion and turbid runoff from arable land.

3.2.1.2 Livestock Farming

Livestock farming involves a number of practices, which may generate sediment, particularly on impermeable soils, by their ill-timed use during and after wet weather. Included are poaching (grazing stock treading the soil surface when moist or wet), and traffic over the land by both animals and machinery. For dairy cattle there is the impact of high stocking rates on pastures, coupled with the twice-daily journey back and forth to the milking parlour, which often causes churned up gateways tracks, verges, hedges, and banks. Many beef cattle and nearly all sheep are outwintered, resulting in poaching by the stock, which seals the soil surface and produces muddy water.

As well as poaching by stock there is vehicular traffic by farmers taking out hay, silage and other forage or checking the stock. Tractors and other vehicles rut and slurry the soil, particularly at gateways, feeding racks and other bottlenecks, providing sediment and channels for its transport. Feeding racks are often placed in vulnerable positions near to streams to give stock easy access to drinking water. Similar slurrying and rutting takes place around big bale stores. Illustration of a number of aspects of sediment entering or approaching watercourses in association with livestock are contained in the Southwest Wales case study quoted below.

Outdoor pig keeping has expanded in recent years. Unlike other outdoor livestock enterprises, pigs remain in the same paddocks for around 2 years. These piggeries can provide extreme examples of the risks of sediment generation from livestock. The pigs puddle and poach the soil, accelerating runoff. Additionally there is frequent vehicular traffic along the access races to them, encouraging turbid runoff and transferring it downslope along ruts.

Wastes from housed cattle, pigs, and poultry are commonly spread to land. Much ill-timed spreading takes place in late autumn and winter, when the crops (grass included) are unable to use the applied nutrients, and the soil is wet or frozen, posing a high runoff risk. Application then is in breach of the spirit of the Code of Good Agricultural Practice, and has a dual effect in sediment generation. Soil damage by spreaders, as described above, releases and transports soil-derived sediment, while runoff can transfer organic particles, which once in water may behave similarly to silt/clay particles in the process of gravel intrusion. Slurries, a very common form of livestock waste, are more susceptible to runoff transfer into water than solid wastes, such as straw-based farmyard manure. Low-rate irrigation (LRI) is common for disposal of dilute farm wastes, (dirty water) from dairy washings, yard runoff, etc. LRI systems rarely have storage. Therefore, they are used year round, even in very wet weather. Also LRI equipment is used frequently for spreading liquors separated from slurries, making available more potential organic sediment, as well as other pollutants (BOD, NH_4).

The effect of livestock on riverbanks has widespread recognition among Agency staff and has attracted substantial remedial activity in many catchments. It should also be commented that access to ditches and minor water courses by cattle and sheep is commonplace in livestock farming areas, having comparable impacts on banks there to those along rivers.

Many of the impacts of *novel land uses* are similar. Wet weather use of the land has the same results whether the impact is from dairy or beef cattle, sheep, outdoor (supposedly environmentally friendly) pigs, ostriches, water buffaloes, and llama, etc. Where siting is on impermeable or waterlogged soils, the effects are much more severe.

3.2.1.3 Land Drainage

Land drainage is an instinctive response by the farmer to the need for increased food production. Probably begun by the Romans, it has involved, in addition to canalisation of watercourses, the excavation of ditches and surface grips, and burial of field drains. Early field drains were built of stones and brushwood. Since the 19th century, various baked clay tiles and pipes were used. From the 1960s, continuous pipe of slotted plastic has become the standard material for drains. During and since the Second World War, British agriculture saw unprecedented investment in land drainage. Encouraged by agricultural mechanisation, most of it was supported by generous grants from government, in an era when food production from home resources was at least a politically desirable contribution to self-sufficiency, and at times a stark matter of survival. In the last 10 years, grant aid has been discontinued, resulting in a large reduction in land drainage installation.

The main strategies were the lowering of water tables in groundwater-affected soils and the improved permeability of otherwise impermeable, surface wet soils. When draining permeable soils, ditch and pipe drainage exacerbated by pumped outfalls, produce a rapid and drastic response. On impermeable soil, benefits are worthwhile, but less dramatic, and installation of ditches and field drainpipes usually needs supplementation with secondary treatments. These secondary treatments comprise mole ploughing (the drawing of semi-permanent, continuous, cylindrical channels through stable, clayey subsoils) and subsoiling (the disruption of dense, impermeable subsoils to increase their porosity). Effective drainage of such land requires gravel backfill over the drains to connect the pipes to the surface or to the secondary drainage work, although not always done, particularly on small grassland farms.

Seen from an environmental standpoint, agricultural drainage systems designed to remove water from the soil surface and profile have often proved equally effective in transferring pollutants from the land surface into watercourses. In some circumstances, these include soil-derived sediment. While this aspect of soil erosion is little studied in this country, there are several pertinent points. In its pristine state, soil can provide a very effective filter, removing sediment as water percolates through it. However, where there is opportunity for preferential flow, the matrix of the soil can be quickly bypassed. Bypass flow can be a natural property of the soil or it can be created artificially by the farmer. Clayey soils in all but the highest and wettest parts of England and Wales have subsoil fissures that open by shrinkage in dry, summer weather. In the autumn, bypass flow goes down these fissures until the soil matrix re-wets and swells. Worm and other animal burrows and pores left by roots provide other pathways for rapid preferential movement of water through many soils. Drainage works, including secondary treatments, similarly provide bypass routes.

Delivery of sediment from field drains can be substantial. There is evidence, that in at least some circumstances, it is topsoil material originally mobilised by rain impact, surface runoff, and sheet erosion that has remained in suspension in water reaching the drains via rapid bypass routes in the soil. Relationships are likely between amounts of sediment transferred this way and soil textures and free-lime contents. These come about through the initial mobilisation of soil material in both top- and sub-soils and the maintenance of open, natural bypass fissures. Laying field drains using clay tiles and pipes requires careful butting of each (30cm long) pipe, to minimise intrusion of soil material from the trench sides. In unstable soils, sediment intrusion into field drainpipes is prevented only by protection with fibre or coarse mineral filter covers. Installation to this standard is not always achieved in agricultural drainage.

Within the field, land drainage can reduce runoff responses to rainfall by removing surplus soil water received from previous events or by increasing soil porosity and storage capacity if secondary treatments have been carried out. However at a slightly larger scale associated "improvements" to ditches and minor watercourses are likely to counter that effect (Robinson, 1990) by speeding up water movement.

3.2.1.4 Ditch and Bank Erosion

Ditches can be sources of sediment. Flowing water scours soil from the ditch floor; and where the banks are incompletely covered by vegetation, soil can spall into the ditch. This occurs quickly when grass is shaded-out by ditch-side shrubs. Access by livestock or use of the ditch for burrows by wild animals encourages further sediment. In general, this source of sediment is greater in livestock farming areas, which also tend to be in wetter districts and have more drain flow. Where medieval enclosure of the land gives fields boundaries that are several hundred years old, continued erosion of ditches has produced gullies sometimes meters deep. These can be sufficiently common to have dialect names to describe them; e.g. "goyle" in Somerset. In arable areas, hedges are fewer and ditch banks are routinely mown, maintaining a grassy sward. This minimizes the scope for erosion. In the uplands shallow grips dug as surface drains are known (Stewart, 1963) to have eroded into gullies meters deep within a decade or so.

Damage to the banks of rivers and streams were described in the introduction to this section. Trampling by livestock of already vulnerable, often naturally steep or vertical banks is clearly a means by which agriculture can introduce soil material into watercourses. Erosion of banks by flowing water during spates is undoubtedly a natural geomorphological process, occurring in non-agricultural as well as farmed catchments. Whether agriculture has modified runoff regimes, therefore increasing stream discharges and subsequent bank erosion, is an issue that deserves careful research.

3.2.1.5 General

Sheep and cattle graze most of the uplands in England and Wales. In places, overgrazing, damage by foot and vehicle traffic, air pollution and peat cutting have exposed the soil to erosion through degradation of the vegetation cover. At times, this is on spectacular scales, with marked sedimentation in some lakes and reservoirs. While part of this erosion is of historical origin, sheep numbers in the uplands have increased substantially post-war in response to headage payments.

Overgrazing can destroy the protective cover of vegetation. Exclusion of stock can result in re-establishment of upland vegetation.

Compared with the dramatic scale of soil erosion that occurs in some countries overseas, soil erosion on agricultural land in England and Wales may be on a lesser scale. While the RCEP (1996) took the position that erosion of arable land is not a major problem, they did acknowledge some irreversible off-farm effects. A further step forward will be for agriculturists to see soil erosion primarily as the transfer of particulates, just as much from turbid runoff or drain discharges as from easily identified rills and gullies in arable fields.

There is not a culture of soil and water conservation in agriculture in the UK, either on farms or administratively. In the past tenants of some estates were required to redistribute eroded soil back across fields, or pay dilapidations to the landlord. These have largely lapsed by default. Many tenancy agreements include clauses regarding "good husbandry", with at least one major landowner considering re-interpretation of this to encourage environmental protection. At the advisory level, charging and commercialisation came about in the 1980s and '90s. At the same time, environmentally driven needs for re-education of most landusers and their advisors became apparent. Yet so far, neither the infrastructure nor the resources for that re-education have been available on an appropriate scale. While the Codes of Good Agricultural Practice set standards for protection of water, soil and air, they are expressed in broad terms. They stop short of making recommendations for specific cropping and livestock management activities. In the United States, Australia, and New Zealand, detailed best management practices (BMPs) are encouraged as a means of protecting water and conserving soil.

Implementation of BMPs, as identified in the Environment Agency's R&D Report P40 (1997), possibly through whole farm management planning, could be expected to reduce agricultural emissions of sediment. Inevitably, there will be costs to farming and inertia in uptake, although changes in approach, such as waste minimization or minimal tillage, may provide long term savings in fertiliser, fuel and other costs. Recommendation 26 by the RCEP (1996), attaching environmental conditions to CAP payments (cross compliance), could be a powerful spur to adoption of BMPs. In some catchments early attempts are being made to encourage BMP uptake, as in the Agency's "Landcare" project in the Hampshire Avon area, and the Westcountry Rivers Trust's "Tamar 2,000".

3.2.2 Non-agricultural sources of sediment:

There is potential for accelerated generation of fine sediment in non-agricultural uses of rural land. These require consideration in order that the overall issue of sediment pollution of spawning gravel can be understood and managed in a balanced way. In many circumstances, it may be clear where the sources of sediment are. Elsewhere resort to mineralogical, geochemical, or related methods of fingerprinting of fine sediment may be necessary. For some sources the Agency or other appropriate bodies have developed or are developing codes of practice aimed at prevention or mitigation.

3.2.2.1 Aquaculture

Fish farms can, within the terms of their consents, discharge steady streams of low-density organic matter of fecal and other origins, much of which is relatively coarse (up to a few mm across). Such material was observed in the water column and depositing on the bed of the Test near Romsey, but it is not clear whether it enters bed gravel at the egg zone level.

Watercress growing has a long history in various groundwater fed catchments, especially in the Chalk country of southern England. Like many other aspects of horticulture, market forces have encouraged considerable sophistication in the enterprise. It is known that cress farms can be sources of sediment in watercourses.

Duck rearing preparatory to release for sporting shooting was being carried out on a side stream of at least one salmonid river visited. Intensive traffic and concentration of birds resulted in localised, severe damage to the stream banks, releasing sediment into the watercourse, which appears to have partly re-deposited further downstream. This activity is better suited to lakes and ponds well isolated from sensitive watercourses.

3.2.2.2 Forestry

Much of the land used for forestry is on ground poorly suited to agriculture, in and around the uplands. Siting is commonly either on very steep, often very acid but freely draining soils, or on wet land which may be impermeable, affected by high groundwater-tables or on blanket peat. As with other forms of land use, the risk of sediment generation from forestry comes with the working or disturbance of the soil, particularly under wet conditions. Inherently wet soil in or near the uplands, with their long wet seasons, are particularly vulnerable, and are only safely workable during very dry summer weather. Various work quoted by Nisbet (1996) suggests a 2 to 5 fold increase in sediment following afforestation of moorland catchments. Preparation of the land for planting by cultivation or draining presents risks initially, while further disturbance comes with the construction and use of roadways and in harvesting. The impacts of these operations can be minimised by careful management that plans and executes operations with full consideration of site conditions.

Ploughing and draining are particularly hazardous wherever they result in increased water flow, as this encourages soil erosion and sediment delivery to watercourses. Good practice avoids any unnecessary overcultivation or other disturbance of the soil. Where furrows or drains are needed, they should be close to the contour with minimal gradients along them. Sensitively designed and constructed buffer strips should reduce the amounts of sediment reaching streams, but as in other situations, the finer sediment is least likely to be removed. Harvesting of trees involves heavy machinery working on the land. Poorly timed work will compact and rut wet ground, resulting in accelerated runoff, soil erosion and sediment transfer. Damage to drainage ditches and watercourses is a further risk when felling and clearing. Forest roadways are both a source and means of transport of sediment. Soil left bare in cuttings, embankments, ditches, etc. during road construction is easily eroded. Vehicle movements in wet weather on non-metalled road surfaces generates mud and turbid runoff, which can flow along them or their drainage systems, often adding further erosion. Crossing points of ditches, streams and rivers are particularly vulnerable.

A detailed code of good practice for forestry is provided by the Forestry Commission's "Forests and water guidelines" (1993). The Agency has carried out R&D on the production of sediment from forestry operations. It is working with the forestry industry to produce a BMP manual and a training programme for its staff. When fully implemented these will raise standards of practice and encourage planning of operations in ways that are sensitive to specific site conditions.

3.2.2.3 New construction

The areal extent of soil disturbance from new construction sites for transport, industry, housing, etc. is at any single time limited, compared with agriculture. Nevertheless there is substantial potential for pollution following sediment generation and transfer as the work involves heavy machinery and continues almost regardless of ground conditions. Often much of the work goes on after storm water drainage has been installed, providing ready access for turbid emissions to watercourses. In the past, there has been little attempt to control sediment from construction sites and awareness of them as sources of particulate pollution remains low. In the course of the regional visits, construction of the second runway at Manchester airport and the Newbury bypass were seen. Serious attempts have been made to avoid turbid discharges to watercourses by planning and management of the projects. These are examples of the Agency's developing policy of active involvement with the industry from the design stage onwards. Recently this has taken the form of the 1997 "Building a cleaner future" national campaign and the production of a range of Pollution Prevention Guidance (PPG) leaflets.

3.2.2.4 Roads

Soil erosion of road cuttings, embankments, and ditches can contribute turbid runoff. Modern roads are built with drainage systems that can rapidly transfer sediment to watercourses. In some cases, stilling ponds are incorporated to minimise sediment pollution. Other sediment comes from the encroachment of traffic onto verges, while undrained, minor roads often serve as conduits for water, with further sediment eroded where the flow impinges on the road verges. While rubber detritus washed from roads may be environmentally beneficial in adsorbing chemicals draining from the roads, the possibility of it contributing to the fine sediment intruding gravel should be recognised.

3.2.2.5 Mineral extraction

Quarrying and opencast working for a range of minerals includes aggregate/gravel, sand, peat, coal, china, ball, and brick clays, along with other materials. In many circumstances, these workings have the potential to generate turbid water. In some, use of water is an integral part of the process and the undertakings are subject to controls over discharges to watercourse. In others turbid runoff is incidental, associated with machinery traffic and disturbance of soil and rock under wet conditions. Extraction of gravel from the beds of streams is common. It is done both commercially and more casually by riparian landowners and tenants. The risk of immediate release of fine sediment during the operation is obvious. In addition the long-term destabilisation of the bed and channel becomes a serious possibility, triggering severe bank erosion and changes in the channel.

3.2.2.6 Other land use

The processes of soil disturbance can cause compaction with associated loss of infiltration and enhanced runoff. These processes take place when the soil is disturbed for military or leisure use as for agriculture or forestry use. Hooves, feet, wheels and tracks have the same effect on wet ground regardless, slurrying the soil, damaging, wearing and breaching swards and producing channels and ruts.

Military manoeuvres and vehicle testing are carried out in some salmonid catchments. The need to operate regardless of ground conditions, often with large numbers of very large and powerful equipment inevitably produces turbid water and trackways for it to run downslope, threatening watercourses. In recent years, some improvements have been made on some ranges. Metalled roads, bridges, settlement lagoons, etc. were built in the more sensitive sites. However, where the training grounds are on national parks conflicts of interest can develop. For example, the policy of benign neglect for roads on some ranges may discourage vehicular access by the public, but will most probably increase sediment generation from the degraded roads.

The erosion of soil along some popular footpaths and bridleways, such as the Pennine Way has been recognised as a problem for decades. However, the scale of these effects and the potential for sediment transfer has grown with the expansion of public enthusiasm for outdoor activities and with the availability of all-terrain vehicles.

Much of the canal network has been revived for recreational use, with many derelict sections restored in the past 30 or 40 years. An example of the possible effect of this is the reopening of the Kennet Avon canal in recent years, which has encouraged an upsurge in boat traffic. Some anglers fishing in the River Kennet claim that this has resulted in discharges that are more turbid. The turbidity came from the canal to the river, degrading the salmonid habitat to the advantage of carp and other competitors.

3.2.2.7 Connections between land-derived sediment and watercourses.

Any sediment mobilised by landuse becomes significant to the aquatic environment if there is a serious prospect of it reaching watercourses. Its delivery depends on interactions of soil and site hydrology, weather and season, and landuse activities.

In landscapes with impermeable soils, the risk of that happening is very high. The natural drainage network is dense, with numerous rivers and streams. Potential for water storage within the soil is intrinsically small and water is transferred rapidly to watercourses. In the winter, this will be in response to all but the lightest rainfall. Farmers have always sought to improve drainage by ditching, installing land drainpipes, and by secondary drainage treatments of mole ploughing or subsoiling. The vulnerability of such soils to structural damage by ill-timed use of the land, such as cultivation or poaching, can add to the susceptibility to runoff.

Watercourses are much less frequent in landscapes dominated by freely draining soils. However physiographic relief may be greater in such landscapes and relict dry valley networks do remain.

Aside from the relatively restricted areas on alluvial deposits, artificial drainage structures are rare. Runoff and associated sediment release can occur when landuse degrades the surface soil structure or leaves it unprotected by a vegetative cover. In some instances, the runoff will not reach a watercourse, but percolate into the soil beforehand; in others it will. Then it does so via an extended, ephemeral, drainage network, which includes natural features, such as dry valley floors and other concavities, as well as others with man-made origins. These comprise permanent elements, such as hedge lines, gateways, footpaths, tracks, lanes, and roadways; the latter usually with drainage systems connected to watercourses, as well as temporary features including livestock tracks, furrows, cultivation marks, tramlines, wheelings, and ruts. When activated by sufficient rainfall and runoff the extended drainage network can be very effective in transferring fine sediment from the land to water bodies.

3.3 Case studies

Throughout the catchment visits with Agency staff, their views regarding any impacts from rural land use were canvassed. They were also asked for any hard evidence capable of convincing the skeptical or reluctant. As noted above in Section 3.2 many of them are concerned at the extent of bank erosion due to livestock trampling. Where fencing had been used to restrict trampling there was clearly a beneficial effect with swards often recovering and adding protection and cover to the banks. However, beyond several examples of appropriate management of banks based on fencing, hard evidence was in short supply. The main examples of what was obtained are summarised below.

Whenever the potential of sediment derived from the catchment as a whole was discussed with staff, there was enthusiasm to investigate it. What was lacking was any guidance in investigating and recording incidents away from the aquatic environment. The protocol in Appendix A, used by SSLRC, may be helpful in such circumstances.

3.3.1 Southwest Wales

Agency staff (Todd *et al.,* 1997) prepared a photographic report "Soil erosion on south west Wales rivers and sediment entering watercourses" in 1997. It demonstrates some of the causes of sediment mobilisation and transfer to streams and rivers; many of them associated with grassland farming.

Feeding of outwintering cattle and sheep is commonplace, and is often carried out close to watercourses. The repeated tractor traffic to replenish hay or silage, coupled with the concentration of animals feeding, quickly slurries the soil around feeding racks. Such conditions readily give rise to turbid runoff, which often flows along tractor wheelings. Non-metalled tracks muddied by tractors carrying forage and slurry are shown fording the River Sannan, allowing easy entry of mud and turbid runoff into the river. Similar encouragement of runoff is shown along the Geidrych a Sewin stream, tributary to the River Twyi.

Photographs also show the vulnerability of the Afon Garw adjacent to opencast coal mining, it being reported as running black whenever heavy rain falls. Although there is restoration following stream diversion and mining, equally some water management and restoration practices could be altered to better protect the watercourse.

3.3.2 Coughton Brook, Gwent

Purvis (1997) reports on an episodic high turbidity discharge to the Coughton Brook, associated with heavy rain onto potato/field vegetable fields near Ross on Wye, in August 1997. The incident was described with reference to a sequence of photographs. It is known to have been one of a series of similar occurrences in the area. It is reproduced in this report as Appendix B.

On 5 August 1997 the River Wye between Ross and Monmouth was reported (Report 28721) as being red in colour. Investigation revealed a turbid, red plume from the Coughton Brook. Photographs in the report show evidence of runoff from a freshly cultivated field having flowed out of the gateway, onto the road and then most into the watercourse. A further runoff incident from an established crop of bed grown onions nearby followed a similar pathway to the watercourse.

In addition, routine water quality samples taken on the 5 August from the Coughton Brook showed suspended solids at 1,555 ppm. Background amounts were 8ppm on 14 July and 18ppm on 29 August. Interpretation of Fig 4-1 suggests maintained concentrations of this order during the incubation period would be lethal within six or seven days.

3.3.3 River Lod, Sussex

A sequence of photographs taken over about half an hour on 1 February 1995 during a single rainfall event illustrates sediment movement from the land into the River Lod (a tributary of the

Western Rother in Sussex). Turbid water originating in the ruts left on a flat potato field after harvest, followed wheelings and flowed out of the gate into the road. Other turbid runoff passed through the field margin into the road, following it downhill until reaching a road drainage gully, where it discharged into a ditch and then into the river. Water from adjacent leek fields ran off in a similar manner.

Sediment traps excavated alongside the potato field, although proving effective in settling out the very coarse sediment, continued to release turbid water, heavily charged with silt and clay sized particles. Straw bale barriers across the gateway of the leek field had failed to prevent the runoff reaching the road. The presence of both the straw barriers and the silt traps demonstrate that this was not the first occurrence of this kind.

3.3.4 Mount's Bay, Cornwall

Runoff and soil erosion accelerated by winter cropping of daffodils and field vegetables are important contributory conditions for the movement of soil-bound agricultural pesticides into water courses from loamy soils on slatey rocks in west Cornwall (Harrod, 1992). Frequently, runoff generated in fields remote from watercourses was traceable via wheel ruts, trackways etc. across a number of fields into ditches connected to the streams, or onto roads and by the road drainage systems into watercourses.

The measured suspended solid loads of 21 runoff samples from the land, often entering watercourses, were between 58 and 8,000 ppm (median 520, mean 1,102ppm). During the events, suspended solids in the receiving watercourses ranged from 12 to 1720 ppm (median 59, mean 298ppm). Rainfall was between 1.4 and 3.5mm per hour. During dry weather suspended solids in the watercourses were between 2-7ppm. According to Figure 4-1, a median suspended sediment load of 59ppm in runoff events, would reduce the dissolved oxygen to critical levels in a little over 10 days. Lethal levels would be reached in 140 days. This assumes that conditions here are analogous to the Tucannon River.

3.3.5 Scotley and Fingle Brooks, Devon

Development of the A30 trunk road across the head of this catchment in the 1970s caused concern that road runoff was accentuating entry of fine suspended sediment from these clayey catchments into the River Teign. Lack of suspended sediment measurements prior to the road works prevented confirmation of any changes (Harrod, 1990), although there was little evidence to suggest road construction was having any long-term effect. However, the work did provide measurements which indicate the suspension loads during spates. Median value from 153 measurements was 309ppm (mean 467); these ranged from 36 to 3,254ppm, with amounts at low flows around 5ppm. Applying this median suspended solids value to Figure 4-1 suggests that dissolved oxygen will fall to the critical 8 mg/l value in two days at such concentrations of solids. It will fall to 2 mg/l (lethal status to Pacific salmon) after about 12 days.

3.3.6 Sutherland Beck, Yorkshire

Correspondence, supported by photographic evidence, by the Environment Agency and the Forestry Commission concerning silt pollution of this tributary of the Yorkshire Derwent early in 1997, provides an example of the adverse impact of forestry operations. In this instance, sediment generation was largely from vehicle traffic along forest roads. Trucks were entering the beck, along with associated turbid runoff and mud, without the watercourse being protected by stream crossing structures. The Forestry Authority's "Forest and Water Guidelines", which provides information on protection of the aquatic environment, had not been followed by the contractors.

3.4 Conclusions

The photographic evidence and occasional measurements of suspended sediment only establish that sediment yield from agricultural lands does lead to fine sediment in the water column. However, it is not proof that there is a definite connection between agricultural-induced erosion and the decline of salmonids. To do so, requires the following 3-steps of field monitoring and analyses:

1. Sedographs (suspended sediment versus time) of sediment yield incidents in all spawning reaches to be analyzed, especially during the spawning season including particle size distributions of the sediment yield. This is necessary to be able to quantify the direct relationship between agricultural-induced erosion and sediment yield, and the sediment yield and the fine sediment intrusion into the redds.

2. Installation, monitoring, and laboratory analysis of artificial redds during the spawning season. Laboratory analysis of the fine sediment found in the interstices for density, particle size, organic content, etc. and including “fingerprinting” of the source of fine sediment found in the interstices. Fingerprinting is necessary to determine if the fine sediment originated from arable land, pastureland, bed and bank of the stream, instream gravel mining, open cast mining, urbanization, etc. This will establish how much of the interstitial fine sediment can be directly attributed to agriculture.

3. Determining the emergent fry-to-smolt relationship including the current carrying capacity. This will determine the relative importance of the spawning versus rearing habitat.

The site visits only provided a few photographs and an occasional single suspended sediment sample. Much more obvious is the need to provide hard, scientific proof of the connection between agriculture and the decline of salmonids.

4 TECHNICAL RELATIONSHIPS BETWEEN AGRICULTURE AND SALMONIDS

Agriculture can adversely affect salmonids directly and indirectly in many ways (see Section 3.2.1). Sediment yield from gullies, overgrazing, and arable erosion; removal of riparian vegetation; and uncontrolled access of livestock to stream banks are some of the more serious ways. There are other non-agricultural activities that can have similar effects (see Section 3.2.2) and they need to be understood to properly evaluate, plan, and implement solutions for salmonid restoration. Some of these non-agricultural activities, which can adversely affect salmonid populations in the same manner as the lack of agricultural conservation practices, are: (1) poor forestry practices; (2) overabundance of predators; (3) improper fisheries management; (4) excessive instream gravel mining; and (5) uncontrolled urbanisation and construction

The total life stage for salmonids should be studied for each catchment in which there is interest in preserving or restoring salmonids. Several life stage models exist that can be adapted for use in the UK (Bjornn 1987, Miller 1987)

This section will concentrate on both the salmonid spawning and rearing habitats.

4.1 Sedimentation and Spawning

Table 4-1 Sediment Classes

Particle Class	Size Range (mm)
Gravel	> 2
Coarse Sand	0.6-2
Medium Sand	0.2-0.6
Fine Sand	.060-0.2
Silt	.002-.060
Clay	< .002

Spawning is the first stage in the total-life-stage-cycle of salmonids. Sedimentation processes profoundly affect the survival of salmonids. This subsection is intended to explain the interaction between sedimentation and spawning.

The normal sedimentation processes in gravel bed streams can account for fine sediment found in the interstices. A useful classification for sediment yield and transport analysis is to divide the particle sizes into classes as shown in Table 4-1.

Gravel bed streams can be defined as the presence of gravel size particles sufficient to provide a self-supporting structural framework. It is sufficient if 65 percent or greater of the substrate is gravel. The interstices may be filled with any combination of water and fine sediment (sand, silt, and clay) because this matrix does not provide any structural support to the substrate. The resulting permeability is considerably reduced when fine sediment is present. This greatly retards the flow of water through the interstices. Approximately 10 percent of the substrate volume is actually water; the rest is composed of gravel and fine sediment. Organic matter in the fine sediment, plus any embryo or fry that may have been present before the fine sediment intruded into the interstices, soon consume whatever dissolved oxygen (DO) is in the interstitial water. When fine sediment intrudes into the egg zone, the DO will quickly drop to lethal levels in a matter of hours. This will result in a massive fish kill.

There are only two possible sources for a sediment particle. Either the particle originated within the fluvial stream system (bed and bank erosion) or it came from the catchment landscape (usually sheet and rill erosion and, in many instances, from gully erosion). Most sediment yield from sheet and rill and gully erosion is delivered to the stream as the finer fraction (fine sand, silt, and clay) and is called wash load. Wash load only occurs when there is a surface runoff event that includes suspended sediment that remains in suspension with the water column. The particle size and amount of suspended material that is wash load depends upon the hydrodynamics of the water column. Sediment yield originating from within the stream system is called bed material load and is generally the coarser material (sand and gravel). The presence of any given particle size depends upon the presence of that particle size in the source material.

Bed load is defined as sediment being transported by sliding, rolling, or saltating along the streambed. Suspension is defined as sediment being supported and transported by the water column. Smaller particle sizes can be carried in greater concentration in suspension than the larger sizes.

In the fluvial streams in the UK, it is unlikely that gravel would be transported in suspension; rather it can be expected to move only as bed load. Sand may be transported in either suspension and/or as bed load depending upon the hydraulics. Silt and clay are likely to be transported only in suspension and then only during a surface runoff event. Bed load movement of the gravel is not likely to occur unless the discharge is at near bank full or higher. These higher discharges are a result of a surface runoff event or spate.

When there is bed load, there is likely to be some wash load present. When the discharge decreases after a surface runoff event, any bed load movement settles down and traps some of the suspended sediment within the interstices. Fine sediment is usually found in the interstices. If fine sediment is not present, it was either removed by man or by an aquatic animal (in our case, a salmonid digging a redd).

A female salmonid sweeps the smaller gravel particles and any surrounding interstitial fine sediment up into the flowing column of water when digging a redd (Burner 1951, Chapman 1988). The gravel particle rolls or falls down immediately downstream over any previously deposited eggs, but the fine sediment is swept away (Burner 1951, Chapman 1988). She may not be able to lift the largest particles. These large particles will settle onto the top of the undisturbed substrate and become the basis for the egg zone (Burner 1951, Chapman 1988). The completed substrate contains less fine sediment than the surrounding undisturbed substrate (Chapman 1988). The water can flow down and through the egg zone in recently constructed redds to provide much needed dissolved oxygen throughout the incubation period until subsequent significant intrusion of fine sediment into the redd reduces its the permeability. Depending upon the species and water temperature, the embryo/fry will spend from 60 to 180 days in the substrate. A more complete description of the redd building process with citations can be found in Alonso *et al.* (1996). Their description includes findings from field measurements in the Tucannon River, a tributary in the Columbia River Basin.

Unfortunately, there is another way for fine sediment to be found in the substrate. When a clean gravel substrate exists and a surface runoff event occurs carrying a larger than normal amount of wash load, some fine sediment can be trapped at the bottom of the substrate. This is the intrusion process described by Alonso *et al.* (1996). The bottom of a redd is the egg zone and it can contain upwards of 5,000 embryo or fry in a single redd. The sediment intrusion caused by a surface runoff event can cause a major fish kill. This process is insidious because it cannot be seen.

To illustrate the significance of this process, Figure 4-1 was developed. It was generated using the Sediment Intrusion and Dissolved Oxygen (SIDO) computer model (Alonso *et al.* 1996). Since UK stream geometry, hydraulic, and salmonid (atlantic salmon or sea trout) data was not readily available, the input data for Figure 4-1 was taken from published data in the SIDO documentation. This data is based entirely upon chinook salmon and the hydro-geomorphic conditions found in the Tucannon River, a tributary of the Columbia River Basin in the Pacific Northwest of the United States. Therefore the Figure 4-1 is for illustration only and should not be used as shown for analysis of DO in the UK. It will be necessary to rerun SIDO for UK conditions.

The Coughton Incident (see Section 8) shows a measured suspended concentration of 1500 ppm. It can be seen from Figure 4-1 and the lethal curve (DO=2mg/l) that it would only take 7 days at 1500 ppm to completely kill all the embryo/fry in a redd under that discharge. It can also be seen that mortality due to a reduction in DO begins in less than a day by using the critical curve (DO=8mg/l).

Figure 4-1: Dissolved Oxygen in a Salmonid Redd

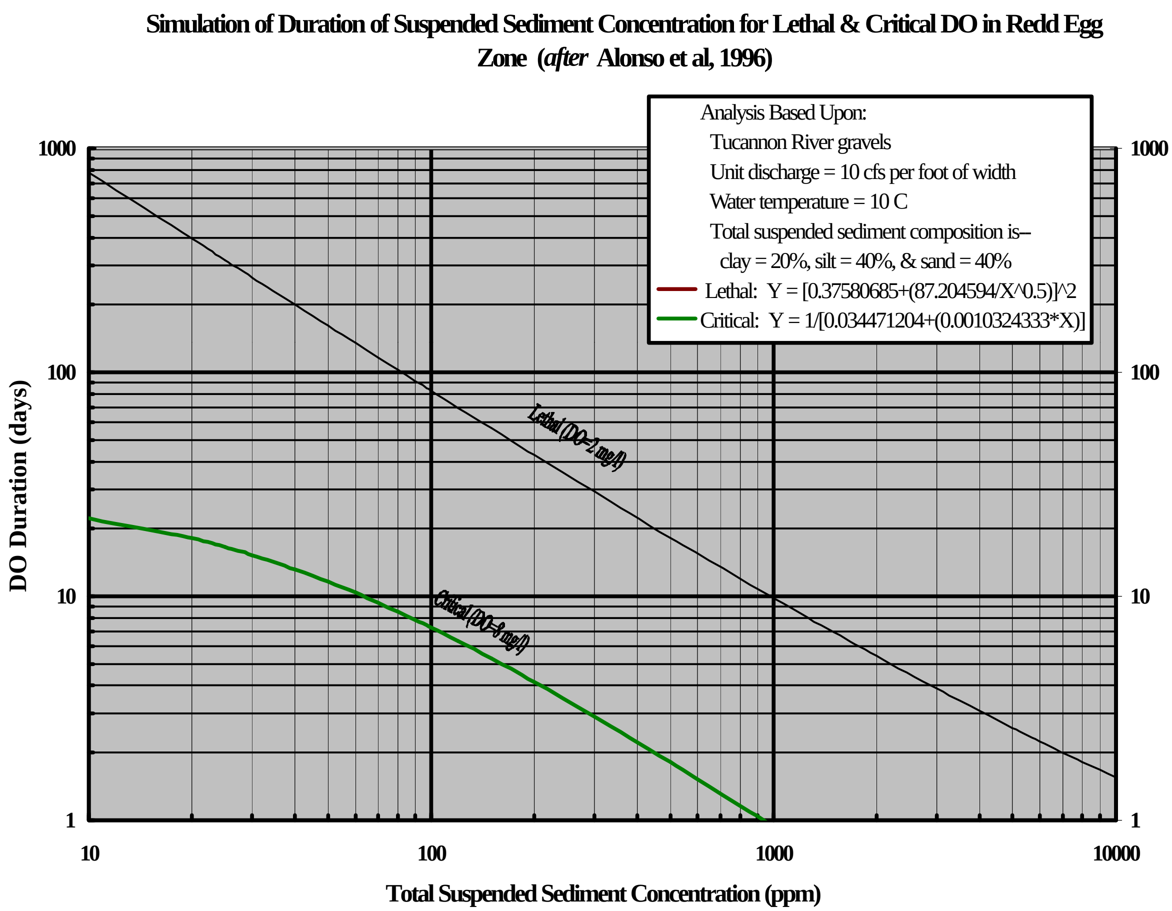


Figure 4-1 is to be used for illustration purposes only since it is based entirely upon chinook salmon and the hydro-geomorphic conditions found in the Tucannon River, a tributary of the Columbia River Basin in the Pacific Northwest of the US.

4.2 Rearing Habitat

The rearing habitat is very important to the survival of salmonids. It is the second stage in the total-life-stage-cycle of salmonids. Depending upon the species and water temperature, the anadromous salmonids (salmon and sea trout) will spend from one to 7 years in their freshwater environment as juveniles before becoming smolts and migrating to the ocean.

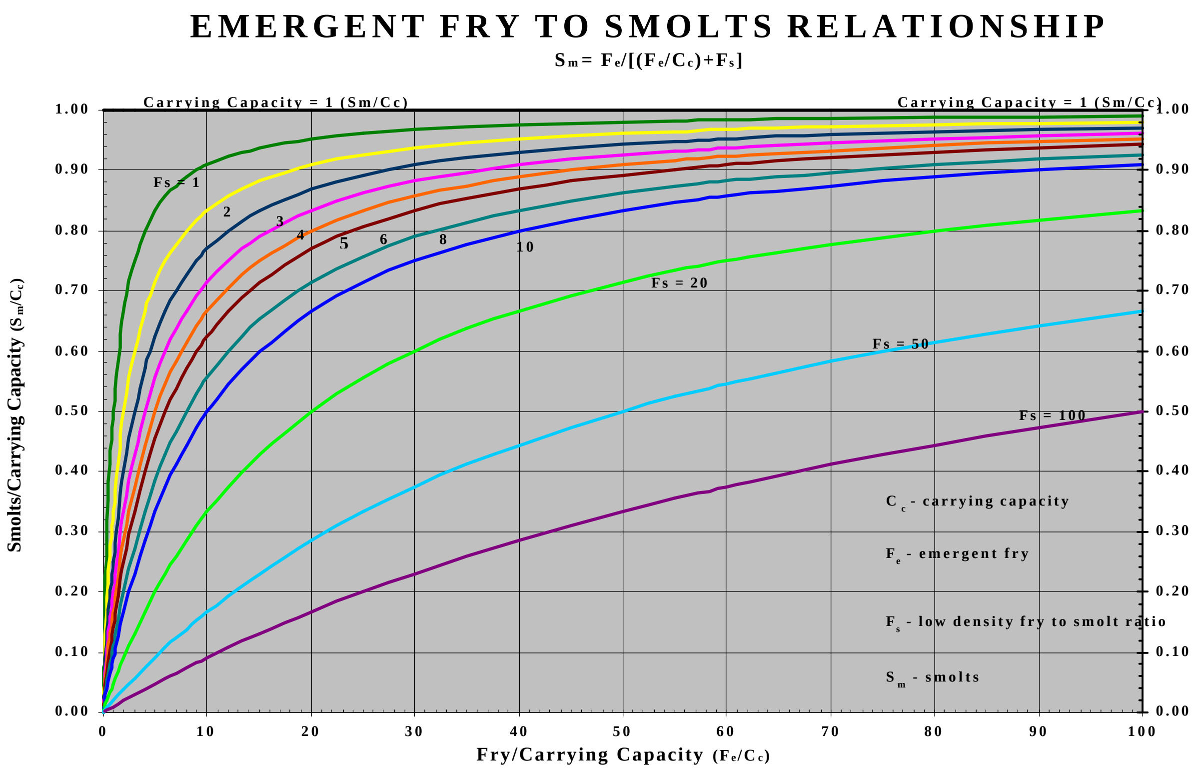
The origin of pollutants within the stream system does not change their impact on the environment. Sediment particles from any source behave the same. However, any adsorbed chemicals are likely to be related to the source.

Many factors affect the viability of the rearing habitat. Reducing the amount of sediment, ensuring the presence of riparian vegetation, keeping a proper balance in the numbers of predators, preventing toxic chemicals, and stabilizing the bed and banks are a few.

Figure 4-2 was adapted from Bjornn's (1987) total life stage model. It is used to illustrate that the number of smolts (S_m) is related to the number of emergent fry (F_e). This relationship is a function of the carrying capacity (C_c) which reflects the stream hydro-geomorphologic and related physical conditions (reach-by-reach), and the expected low-density fry-to-smolt ratio (F_s) which is a function of number of predators, etc. An important point is not to double count a factor; i.e., the predator factor is in the F_s variable, not the C_c variable.

The F_e-to-S_m relationship was converted to a non-dimensional basis (F_e/C_c and S_m/C_c) by dividing the relationship equation through by C_c to be independent of any specific stream system's carrying capacity.

Figure 4-2: Rearing Habitat



Sedimentation can affect the rearing habitat in multiple ways. One is to fill the substrate so that recently emerged fry cannot find the necessary cover to hide or move into the interstices if the water temperature drops below the minimum requirement (approximately 5°C). Another is to fill the substrate so that abnormal aquatic vegetation (weeds) take root and change the macroinvertebrates—possibly adversely impacting the food chain.

Riparian vegetation plays an important role in optimizing the carrying capacity. Trees along the bank together with a buffer strip (optimally 10 m) provide stable banks, shade to keep the water from getting too warm, and a source for food (insects, etc.) to drop into the water.

Preventing toxic chemicals from entering the stream is obviously important. The results of toxic spills are often dramatic mostly because they are easily seen and frequently are widely published.

Bed and bank erosion is very evident when livestock have unlimited access to the stream. Fencing, while providing limited access for livestock, is an excellent and standard solution. The effects of downstream gravel withdrawal on bed and band stability are not so evident. Removal of gravel from the streambed encourages bed load movement upstream. This degradation in turn undercuts the banks, which increases the meander rate and can become a major source of sediment in the stream. The amount of bed and bank erosion may be only a fraction of that due to sheet and rill and gullies, but it is delivered directly to the stream whereas the coarser fraction of eroded material from the landscape deposits in the fields with its finer fraction being delivered to the stream. Therefore the percentage of the very fine particle size classes (silt and clay) from the bed and banks tend to be lower then the sediment yield from other sources.

4.3 Conclusions

It is important to determine all the limiting factors in both the spawning and rearing habitat in order to understand all the steps needed to correct an existing problem in or to restore salmonids to a given catchment or subcatchment. For example, preventing fine sediment from intruding into a redd but not limiting the number of predators would only increase the number of predators further by providing them more food. That is why a holistic catchment approach, which includes both spawning and rearing habitats and all potential sources of pollutants, is absolutely necessary.

5 FINDINGS AND RECOMMENDATIONS

5.1 Introduction.

Following ten weeks of site visits and numerous consultations with Agency staff and other knowledgeable scientists, it is apparent that there is:

- sufficient evidence to convince knowledgeable groups (Agency and environmental interests) that there is a significant linkage between agriculture-induced sediment and the loss of salmonids to be of national concern; and
- **not** sufficient evidence to convince other special interest groups (agricultural, governmental, and political).

We believe that the Agency should vigorously pursue the prevention of further loss of salmonid fisheries and their restoration where feasible and desirable, by:

- continuing to collect, analyse, and collate the necessary technical data that will provide the sound technical advice to management and will lead to convincing proof to other special interest groups;
- improving co-operation and communication among Agency staff particularly Fisheries, Water Quality, Flood Defence and Conservation
- providing technical training for its personnel;
- seeking outside expertise from non-Agency as well as non-UK technical specialists;
- assigning the responsibility to the National Salmon Centre (NSC) for planning, managing, coordinating, and carrying out the set of recommended technical procedures.

5.2 Evidence

This subsection is to recommend a set of procedures that would lead to establishing sound scientific proof regarding the connection between sediment, its source, and the loss of salmonid habitat. Agricultural-induced erosion is believed to be the primary source of sediment entering the redds during the incubation period for salmonids. A principal source of the finer-fraction of this sediment is erosion from arable and grazing lands although there is considerable visible evidence of unstable banks due to unlimited access of livestock.

It is recommended that the following sets of procedures are followed:

- Procedure No. 1 - Data collection;
- Procedure No. 2 - Risk assessment; and
- Procedure No. 3 - Risk analysis.

5.2.1 Data collection

The purpose of the first set of procedures is to collect the detailed data needed at the field level to understand the physical and biological cause and effect between sediment and the decline in salmonids and to document these relationships. The immediate detailed field procedure is to prove without a doubt that fine sediment is a cause of loss of salmonids within the redd. That will require recovery of undisturbed redd gravel by freeze-coring (or its equivalent) to determine the degree of sediment intrusion. A second need is to establish the relationship of rearing habitat to the decline of salmonids. A third need is to document any pollution incidents leading to the loss of salmonids.

Procedure A: Installation, monitoring, and sampling artificial redds is the key to sound scientific proof as well as the nexus for technical and management decisions. Install artificial redds and:

- Locate with GPS as well as survey;
- Send freeze-cores to laboratory (particle size analysis, etc. and fingerprint fine sediment [Foster and Walling 1994]) to determine the catchment source, i.e., whether sediment is from arable land, grassland, bed and bank erosion, urban drainage, etc. (NB methods of freeze-coring and analytical methods and categories should be standardized); and
- Collect collateral data (DO, suspended sediment, etc.)

Procedure B: In some cases, the rearing habitat may be the limiting freshwater factor. Modify Bjorn's (1987) emergent fry-to-smolt relationship for UK use and determine:

- Carrying capacity (existing and feasible potential); and
- Low-density emergent fry-to-smolt ratio.

Procedure C: Documenting new incidents systematically and in full will help provide direct linkage between suspended sediment and its catchment source to include documentation, measurements, analyses and photography of:

- discharges and their routes/fates;
- water samples;
- site physical properties; areal extent, slopes, soils land use, crop and any contributory features, e.g. direction of working, poaching, rutting; and
- weather, particularly rainfall before and during the incident.

Appendix A provides guidance for monitoring land runoff events that might form the basis for a standard approach.

5.2.2 Risk assessment

This procedure should be designed to serve a dual purpose: (1) to assist with gathering the scientific evidence necessary to convince others of the strong correlation between agricultural induced erosion and the decline of salmonids in England and Wales; and (2) to serve as a starting database for the risk analysis procedures.

Risk assessment can be done using GIS with the following data digitized so that they may be overlaid:

- Soils maps with attributes;
- Land use maps with attributes;
- Digitized terrain maps; and
- Fisheries data

5.2.3 Risk analysis

This set of procedures is designed to provide specific catchment-by-catchment information regarding: (1) the specific cause of decline in salmonids; (2) what would have to be done to prevent their further decline and restoration; and (3) what the tradeoffs would be (cost/benefit relationships).

Risk analysis is best done with models that have been calibrated and validated with monitored data. The following is a comprehensive set of models that can be adapted for use in the UK:

- Pollutant loading (Cronshey and Theurer 1998)
- Spawning (Alonso *et al.* 1996, Alonso *et al.* 1998, Miller *et al.* 1998);
- Emergent fry-to-smolt (Bjorn 1987); and
- Return spawners (Bjorn 1987, Miller 1987, and Wyatt and Barnard 1997).

5.2.4 Project management

A technically qualified member of staff, with an identified project co-ordinator, following a comprehensive management-supported plan of work is a necessary component to gather the evidence which will convince others of the connection between agriculture and the decline of salmonids in England and Wales.

It is recommended that the Agency considers:

- adding a full-time staff position to the National Salmon Centre to be the Project Co-ordinator;
- requesting the National Salmon Centre to develop and maintain a plan of work that identifies all the necessary tasks, their relationships, expected duration, and needed resources.

5.3 Management Issues

During our site visits to the various Agency regional and area offices, several management problems were encountered that greatly reduced our efficiency to gather and disseminate information.

In general, it was felt that Agency fisheries field personnel do not have sufficient technical expertise themselves, or ready access to the expertise, to adequately carry out their more complex technical responsibilities; i.e., the biologic, hydrologic, hydraulic, hydrodynamic, and geomorphic interrelationships needed to determine the:

- carrying capacity (existing or potential);
- redds (actual or potential numbers);
- return spawners (actual or sustainable numbers); and
- physiological parameters and limits (critical and lethal).

It was also felt that Agency fisheries field personnel lack sufficient opportunity to communicate among themselves and others; e.g.:

- email and Internet is restricted to internal Agency use;
- insufficient opportunity for exchange of views and experience across regional boundaries; and
- insufficient opportunities exist for technical training and experience for their more complex responsibilities.

It is recommended that the Agency should consider:

- revising their email, Internet, and ftp capability to allow all Agency personnel unrestricted access to outside sources of information;

- holding biannual meetings of their field personnel;
- encouraging interdisciplinary assistance within Agency; and
- tasking the National Salmon Centre to provide or arrange for training of field personnel and arrange for non-Agency and non-UK expertise.

5.4 Mitigation measures

Some interim procedures are being used by fisheries personnel to encourage successful salmonid spawning. Two technical procedures are currently being implemented in the UK which may be helpful under limited conditions.

These are:

- water jetting to clean gravel; and
- raking to loosen gravel.

Raking to loosen the gravel is only necessary when the substrate is either truly "cemented" or sufficiently hardened so that the female cannot loosen each particle because salmonids clean their redds by digging and loosening the gravel nearly a single particle at a time,

Water jetting when more fine sediment yield is to be expected during the incubation period is not effective unless the jetting is sufficiently deep to provide at least one year's worth of storage for the fine sediment intrusion below the egg zone of the redd—i.e., provide a sump for the fine sediment.

It is recommended that these procedures are used with caution and it is recognized that:

- they are costly, temporary, and can be counter-productive; and
- the best solution is to keep the fine sediment out of the stream.

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7 APPENDIX A: SOIL SURVEY AND LAND RESEARCH CENTRE—PROTOCOL FOR *AD HOC* MONITORING OF LAND RUNOFF EVENTS

This requires information on location, time, discharge, water quality, rainfall, and the nature and use of the land. Support the observations with photography/video and mapping.

N.B. Field runoff usually responds very rapidly to rainfall. Be ready to respond similarly!

Commonly the subject will be runoff:

- in a rill or rills/gully
- crossing a field
- in wheel rut(s)
- leaving a field by a gateway,
- leaving a field through a hedge (often there can be several points)
- from land drain outfall(s)
- down a track or road

LOCATION:

- 100m National Grid Ref (including 100km square 2 letter code) is normally sufficient
- Catchment with river and stream names or place, farm, field names

DATE/TIME

DISCHARGE

Conventional measurement (weirs, etc.), is unlikely to be on, and improvisation will be necessary. Consequently some precision may be lost, although the overall scale of events and changes within them will be recorded. Sometimes direct measurement , e.g. by bucket and stopwatch at the end of a pipe, is possible, more often the following have to be measured:

N.B. To avoid errors, measure/ calculate in meters or decimals thereof, not cm or mm.

Flow rate(m/minute) of active channel using:

- flow meter if channel large enough
- tracer, e.g. food dye or oil via pipette bottle, timed over measured distance
- 10 measurements per site

Active channel cross sectional area

- 10 measurements of depth
- 10 measurements of width
- to derive mean cross sectional area (m^2)

Calculation

- Discharge (m^3 or liters/min)= flow(m/min) • mean cross section (m^2)

WATER QUALITY SAMPLES

Suspended solids or chemical, ideally covering:

Places

- where the discharge leaves the field or generating site

- where it enters a watercourse or other sensitive site
- downstream of the entry point, (sufficient distance to allow mixing)
- the receiving watercourse above the entry point

Times

- early in the event
- near to the peak
- as it declines
- Additional measurements from the receiving watercourse to indicate background or baseflow levels. (Timing of these will depend on the watercourse's regime).
- Additional measurements from the discharge if it has a baseflow component, e.g. some land drains.

NB: Combination of results of discharge measurements, with analyzed concentrations, gives you loadings.

RAINFALL

Rarely will there be a local autographic rain gauge. A temporary rain gauge should be put out in anticipation of the event, close to the site. It should be measured as frequently as possible (with times recorded), and particularly with any changes in intensity of the rain.

LAND

A record of the generating area (it may only be part of a field) should give details of:

- areal extent (ha)
- slope
  shapes
  angles/gradients
- soil series ("type"), preferably from detailed 1:25,000 soil maps, failing that National Soil Map or through use of identification keys in Regional Soil Bulletin.

LANDUSE

Again for the generating area note:

- crop
- nature of latest cultivation
- -its direction relative to the slope
- -state of soil surface
  for arable Fig 4, p13 of SSLRC Field Handbook (1997) is useful
  for grass % area poached, depth of hoof marks, whether cattle, sheep etc. or wheelings
- any particular structures, e.g. potato ridges, beds, use of polythene, etc.
- any association with particular features, tramlines, furrows, ruts, etc.

TRANSMISSION ROUTE(S)

Describe and map the route taken by runoff as it leaves the site. Commonly this involves the extended drainage network, which has both natural and man-made components. These include:

- concavities
- dry valley floors
- re-entrants
- land drains and ditches
- cultivation marks, (including furrows, tine and wheel marks, ruts, etc.)

- tracks and paths
- roads and their drainage systems

SINKS

Record anywhere runoff is obstructed in reaching a watercourse, and infiltrates instead. Any escapes from sinks need measurement, as above. The records of sinks can be as important as connections of runoff with watercourses, if the exercise is for quantification of catchment/landscape scale links of land and water, rather than for specific runoff incidents.

RECORDING

Because this is essentially wet weather work, tape recording can be quicker and more convenient than writing. Prior marking of sample bottles is advised.

8 APPENDIX B: TECHNICAL MEMORANDUM

A brief report into an episodic high turbidity discharge to the Coughton Brook, a tributary of the Lower Wye, associated with poor arable land-use practice and heavy rainfall.

8.1 Background.

Dr. Fred Theurer, an experienced civil engineer employed by the U. S. Department of Agriculture is on a fellowship visit to England and Wales (OECD) to look at siltation effects on salmonid spawning habitat arising from rural and use practices. This memo summarizes an incident that occurred on a tributary of the lower Wye during early August 1997 and resulted in a large amount of fine sediment polluting the Coughton (Walford) Brook and having a considerable visual impact on the River Wye below its confluence with the Coughton Brook.

8.2 Report.

The Coughton Brook is a small stream (typically less than 3m wide) draining a small catchment (c. 23 km^2) in the Lower Wye (see Figure 1). The Brook enters the left hand bank of the Wye between Ross on Wye and Monmouth. It is approximately 8 km long and falls some 90 m over this distance from 120 m to 30 m above sea level (average gradient 11m/ km). The brook splits at “Frogmote” with the southern arm flowing north from the northern tip of the Forest of Dean, close to Drybrook. It flows through a steep-sided valley bounded by woodland and arable (pasture) land and has a catchment area of approximately 5 km^2. The other arm flows East then South. Again, although at low altitude, the valley sides are relatively steep but less wooded. A greater proportion of this catchment is put over to arable and market gardening and the catchment area is approximately 7 km^2. From the confluence, the Coughton Brook continues to flow through a steep sided valley where arable farming predominates, to its confluence with the River Wye. Typical crops grown are cereals, onions and potatoes.

There have been no electrofishing surveys of the brook and therefore no relating to fish populations. Experience of fish fauna from neighboring streams suggest that current populations are likely to be dominated by minor species (bullhead and stone loach). Brown trout are likely to be present at low densities whilst salmon are unlikely to utilize brook for spawning. Biological information concerning the Coughton Brook is limited to the 5 yearly General Quality Assessment (GQA) carried out in 1990 and 1995. Results show populations of invertebrates scored lower at the Coughton Brook site in 1995 compared with 1990 but that this difference was not significant, (SE/EAU/96/10.). Interestingly, the Coughton Brook spring score (Class 4- BMWP 26-50) is lower than most other streams in the lower Wye area. Sites in class 4 will typically be categorized by low scoring pollution tolerant genera.

This report relates to an incident, which occurred on the 5th of August 1997. A report was received on this day (at 11:34) that the main river Wye was colored “red” (Report reference 28721). The incident was immediately investigated and revealed that the Coughton Brook was the source of the colour in the main river. The report concluded that the colour resulted from overnight rainfall falling onto fields where crops (potatoes) had recently been harvested. A lack of buffer strips to the fields and cross-contour ploughing had resulted in a ready conduit for highly turbid water to enter the water course via the road and road-side drains.

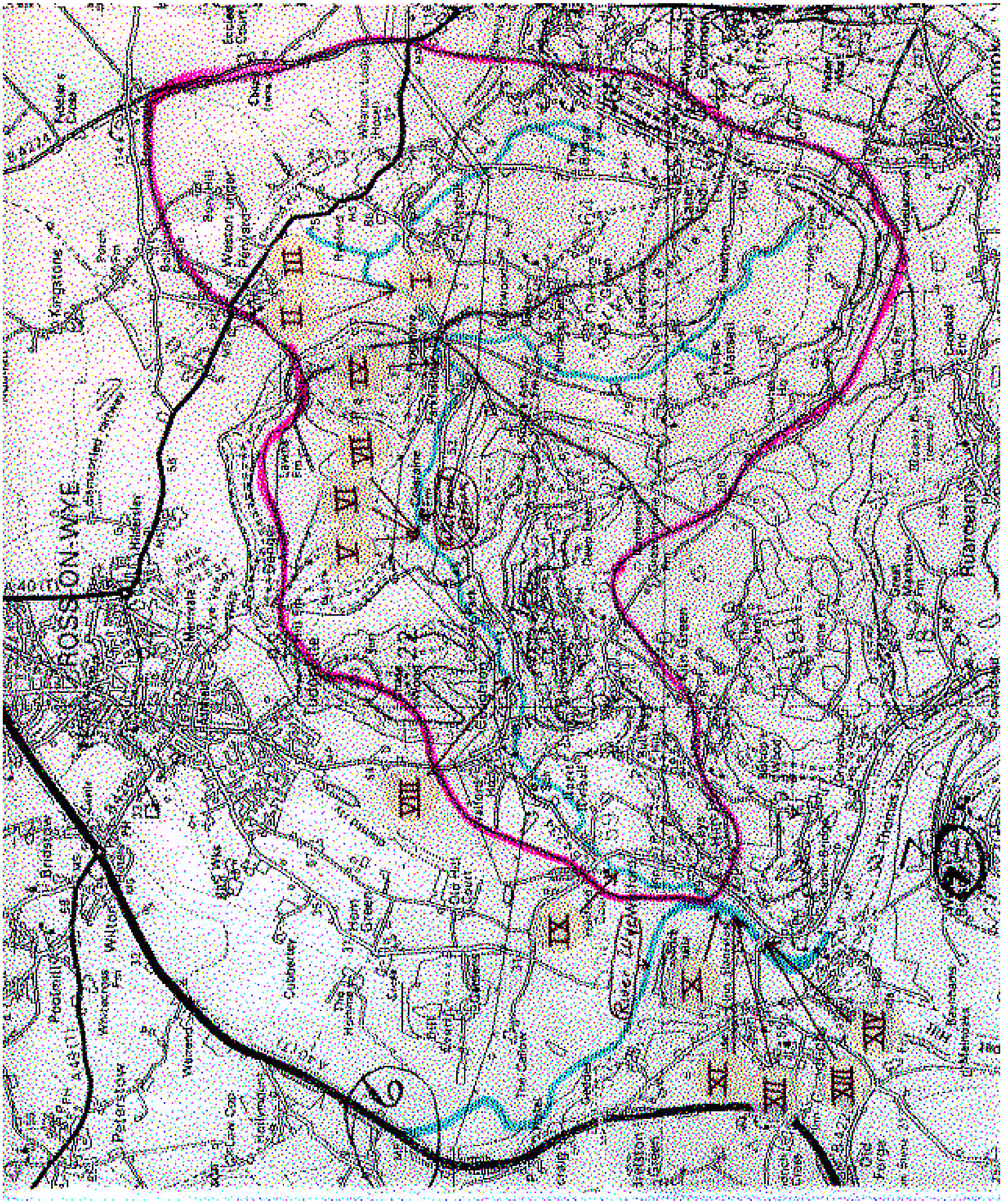

Figure 8-1: Map of Coughton Brook showing photo locations.

Almost exactly one year previously a similar report was received on the same catchment (Report Reference 24628, 31st July 1996). This incident was caused by a leaching irrigator at Cobrey Farm causing a pollution of the brook. In this instance reference is made to a previous visit, two weeks earlier, concerning a similar incident.

Photo I: Coughton Brook—sediment source originating in cultivated field.

Photo II: Coughton Brook—sediment at bottom of field, just before gate.

The incident can be described with reference to a sequence of 13 photographs taken by the investigating officer (John Coombe). The pollution was traced back to recently cultivated fields near Pontshill in the "eastern arm" of the Coughton Brook. Photos I, II, and III all clearly show the aftermath of water containing high solids having flowed across the field (along the cultivated furrows) through the gateway (where puddles and signs of recent silty deposition can be seen) and onto the road, then most probably into the water course.

Photograph IV shows the amount of fine material in the water column in the stream at a point some 0.5 km below the field illustrated in photos I to III. Additional evidence of fine silt entering the stream was also noted further downstream (see photos V, VI and VII). Here an obvious field cropped on the bed system with irrigation mechanisms in place (see pipe in photo V) clearly shows signs of high silt load runoff with an obvious conduit for the dirty water out of the field (photo VI) and onto the road (photo VII). Whilst most of the heavier particles appear to have been deposited at the side of the road during the incident it is probable that the more mobile elements would have run down the road and into the watercourse. Because the photos were taken some time after the cessation of rainfall direct evidence of this pathway (water flowing across the surface) is not present in the photographic record.

Photo III: Coughton Brook—sediment passing through gate.

Photo IV: Coughton Brook—sediment in water column in stream 0.5 km below field in Photo I

Photograph VIII taken some 2.5 km below the uppermost extent of the pollution clearly shows transport of larger particles into the stream and deposition as the water level recedes.

The visual impact of is small stream on the main River Wye is well illustrated by photos X to XIV; close to the confluence the plume of highly turbid water emanating from the brook is clearly visible streaming along the left hand bank (photos X and XI). Within 0.5km the turbidity extends to the full width of the River Wye (see photo XIII).

Supporting Information.

The potable water intake owned by Severn Trent Water Plc (Public Limited Company) at Lower Lydbrook takes turbidity readings each morning. These are reproduced for the period including the incident in Table 1, overleaf.

The values in the above table will need to be interpreted with respect to Wye level data for the same period along with the rainfall data. Notwithstanding this, the results seem to indicate a pulse of elevated turbidity on the 7th of August (unfortunately the records for the 6th are not available, possibly when the greatest results of the incident would be felt on the main river). Please note the results in Table 1 are given in NTU not parts per million and therefore are not directly comparable with the later Agency water quality data.

In addition to the photographic evidence routine water quality samples were taken from the Coughton Brook at Walford Church at 8:30 on the 5th of August. The determinant measured included suspended solids (in ppm). These results show suspended solid levels were extremely high (1,555 ppm). To put this in context, samples on July 14th and August 29th revealed levels of suspended solids of 8 and 18 ppm respectively. In addition, samples were taken from neighboring

Table 1. Severn-Trent Water Plc. Turbidity readings, August 1997.

Date	Suspended solids/ N.T.U.	Comments
3-08-97	3.78	
4-08-97	7.32	<=== Rainfall
5-08-97	4.79	<=== Incident
6-08-97	--	
7-08-97	17.5	<== Peak 1
8-08-97	1.53	
9-08-97	2.14	
10-08-97	21.5	<== Peak 2
11-08-97	16.8	
12-08-97	1.57	
13-08-97	9.2	
14-08-97	8.26	
15-08-97	--	
16-08-97	--	

streams on the 5^{th} of August and are summarized in Table 2 below. In only one of these lower Wye tributaries, the Wriggle Brook were they significantly elevated (596 ppm).

"Background levels" appear to be highest in the Coughton Brook which either reflect natural weathering processes in the catchment or potentially damaging effects of land use practices. Elevated suspended solids levels in all streams on August 5^{th} (except Lewstone Brook) confirm the impact of the rainfall in the locality contributing significantly to the incident.

Summary/ Conclusions.

1. A pollution incident occurred on the 5^{th} of August 1997 which visually impacted on the main Rive Wye over a significant length and which emanated from what is only a minor tributary. The cause of the incident was heavy (?) rainfall transporting fine sediment from poorly managed recently harvested fields

Table 2. Suspended solids results (ppm), routine monitoring samples.

Stream	RHB trib.	14th July	5th August	29th August	Background
Walford Bk	LHB	8	1555	18	13
Wriggle Bk	RHB	6	596	9	8
Lewstone Bk	RHB	8	7	12	10
Gamber Bk	RHB	4	30	3	4
Garren Bk (u/s Gamber Bk confluence)	RHB	7	10	4	6
Garren Bk (d/s Gamber Bk confluence)	RHB	7	30	5	6
Median value	n/a	8	30	7	--

where cross contour ploughing, lack of field edge “buffer systems” and the inappropriate siting of field access points facilitated the transport of turbid water into the water course.

Photo V: Coughton Brook—Additional sediment source from nearby field.

Photo VI: Coughton Brook—sediment transport conduit out of field in Photo V to road drainage system.

2. Suspended solids in the stream were measured at 1,555 ppm. In contrast, background levels in the stream appear to be of the order of 10 ppm which is normal. It is possible that earlier in the incident, peak suspended solid loadings were very much higher than 1,555 ppm.

3. The incident was not associated with a fish kill and was interpreted as having no impact on invertebrates or fish. The former is almost certainly the case, the latter assumption less defensible (however very hard to evaluate). Notwithstanding this, large quantities of fine sediment and some larger particles (see photo VIII) were clearly transported into the stream, with fine particles affecting the main river over several kilometers.

4. Evidence exists that this incident was the latest in a series involving arable farming practices in this area. This may reflect an increase in the amount of such farming in the area and an increasing environmental impact.

Photo VII: Coughton Brook—sediment transport road drainage linkage between field in Photo V and stream.

Photo VIII: Coughton Brook—sediment in stream 2.5 km below fields (Photos I and V).

Photo IX: Coughton Brook—sediment in stream before confluence to River Wye.

Photo X: Coughton Brook—sediment plume from stream in River Wye.

Photo XI: Coughton Brook—sediment plume from stream in River Wye further downstream from Photo X.

Photo XII: Coughton Brook—sediment plume from stream in River Wye further downstream from Photo XI.

Photo XIII: Coughton Brook—sediment from stream extends full width River Wye within 0.5 km downstream confluence.

Photo XIV: Coughton Brook—sediment sample of 1555 ppm taken in River Wye within 1 km confluence.